EMERGING TECHNOLOGIES AND THEIR IMPACT
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Technology Review

AN MIT ENTERPRISE

Special Report

It's Not Too Late

The energy technologies that might forestall global warming already exist. Cleaner coal, smarter nuclear, bioengineered ethanol, and more… Page 37

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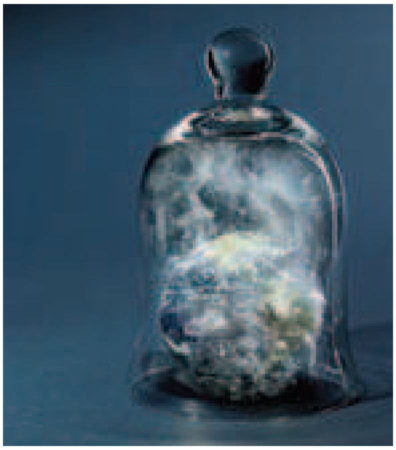
Volume 109, Number 3



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REVOLUTIONARY THINKERS
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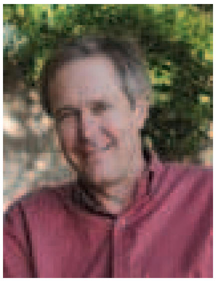
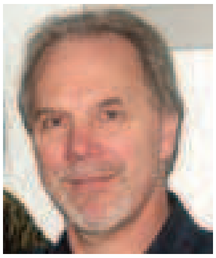
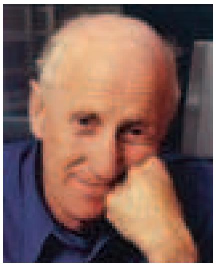
Contributors



James Fallows, a national correspondent for the *Atlantic*, recently took a look at the new wave of online applications sometimes collectively called Web 2.0 *(see "Homo Conexus," p. 76)*. "Thinking about this article," he says, "gave me an excuse to try a lot of sites, features, and applications I'd been curious about but hadn't taken the time to look at seriously. Half of the things I did seemed like fritterware—for instance, proving that I could write an entire article online, just so I could say I did so—but the other half left me thinking, Hmmm, here's another little trick I should pay attention to! I have a shtick in this article about being too old for Web 2.0, but most of these sites would make anyone feel stimulated and young." Fallows's book about the Iraq War, *Blind into Baghdad*, will be published in August. He is now based in Shanghai.

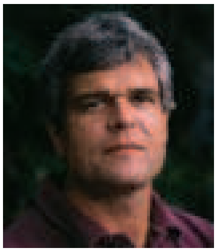


Jamie Shreeve contributed a piece about producing ethanol from plant cellulose, a promising way to make cheap and plentiful fuel from biomass waste *(see "Redesigning Life to Make Ethanol," p. 66)*. "When talking to scientists on the cutting edge of cellulosic-ethanol research," he says, "I was struck by how close they are to bringing technologies to market that could have a really huge impact on one of the most critical issues facing us. The barriers to solving our energy needs and reducing global warming are very real but seem more a matter of societal and political inertia than lack of technological expertise. Thanks to ethanol, Brazil is already free of dependence on foreign oil. Granted, it has a head start with sugarcane—but if Brazil can be energy independent, so can we." Shreeve's most recent book is *The Genome War: How Craig Venter Tried to Capture the Code of Life and Save the World*, named by the *Economist* as a 2004 Book of the Year. He has also written for *National Geographic*, the *New York Times Magazine*, *Wired*, and other publications.



Stewart Brand reviewed *Rainbows End*, the new novel by science fiction luminary Vernor Vinge, whose books have long influenced the imaginations of coders and system designers *(see "Vinge's Singular Vision," p. 86)*. "Studying up on Vinge's interests led me to his recent enthusiasm for Terry Pratchett, the British satirical fantasy writer," he says. "Vinge devoured Pratchett's copious writings, to the point, I suspect, that *Rainbows End* is an homage. Now I'm devouring Pratchett." Brand is the founder of the *Whole Earth Catalog* and cofounder of Well, the Global Business Network, and the Long Now Foundation. In 1973 he was the first to write about hackers (in *Rolling Stone*), and he is the author of *The Media Lab*, *How Buildings Learn*, and *The Clock of the Long Now*.

Matthew L. Wald, who in "The Best Nuclear Option" *(p. 58)* expounds the advantages of current nuclear technology over the Bush administration's Global Nuclear Energy Partnership, has been writing about nuclear energy and nuclear-weapons materials for the *New York Times* since 1979. "Nuclear power as it exists today was fossilized in early-1970s designs," he says. "The commercial industry would like to build new [reactors], incorporating their last 40 years of experience, but the Energy Department has gone off on a noncommercial tangent of uncertain feasibility and relevance."



Mark Bowen profiled climate scientist James Hansen, who says he's being muzzled by politicians *(see "The Messenger," p. 38)*. "I was impressed by Hansen's modesty and honesty," says Bowen. "The way he called attention to even the slightest errors I made in interpreting his work, and his courteous treatment of critics, taught me not only about the honesty required to tackle scientific problems but also about the courage it takes to lead an honest life." Bowen has written for *Natural History* and *Climbing* and recently published his first book, *Thin Ice: Unlocking the Secrets of Climate in the World's Highest Mountains*.

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Sony and Spyware

I just read Wade Roush's piece on Sony and the rootkit affair *("Inside the Spyware Scandal," May/June 2006)*, and I was curious about his decision not to discuss the spyware made by SunnComm, whose MediaMax DRM was also a cause of legal action against Sony BMG. SunnComm made spyware DRM software that phoned Sony and let them know what you'd been listening to, and when you ran their uninstaller, it left your PC vulnerable, so you could be hijacked just by looking at a malicious Web page. Even worse, SunnComm installed its malware even if you declined the user agreement and never played or copied the disc.

Also missing was material about the labels under Sony BMG that decried the use of DRM and complained that corporate was hurting their customers. I was also looking for some balance on the DRM stuff from an organization like the Electronic Frontier Foundation; surely EFF was highly relevant to the story, since it was key to the class action settlement Sony reached.

All in all, this seemed like a very incomplete account, especially for a postmortem so long after the dust had settled. It seemed to me to take too many of Sony's claims at face value without delving into the lessons to be learned from the most significant DRM debacle of the decade.

Cory Doctorow
London, England

"Inside the Spyware Scandal" focused entirely on Windows/PC systems. I would be interested to know whether the software on the music CDs attempted an analogous intrusion on other operating systems, particularly Mac OS X.

Brian Aull
Lexington, MA

Wade Roush responds: Regarding Mr. Doctorow's letter: the article made it clear that the same Sony BMG CDs that contained First 4 Internet's XCP copy protection software also contained a dual Windows/Mac OS X program called MediaMax, from SunnComm. To answer Mr. Aull's question: MediaMax did not employ a rootkit, as XCP did, but did attempt an analogous intrusion. As Doctorow and other critics have pointed out, MediaMax installed itself even if users declined the license agreement, came without an uninstaller, and spied on users by sending their Internet addresses to SunnComm servers when they played protected CDs. The uninstall utility that SunnComm eventually developed to allow consumers to remove MediaMax from Windows PCs created a security vulnerability that exposed their computers to hacker intrusions, but this problem did not affect Macintosh computers.

Legitimate Complaints about Rootkits

I was very surprised by Jason Pontin's comment in his "From the Editor" column regarding the Sony rootkit that "the complaints [from customers whose computers were infected] were much more heated than any damage to users' computers warranted."

The common early "repair" for the rootkit-damaged computers was to reinstall Windows. This is a hair-raising task even for those rare few of us who try to maintain proper and timely computer backups—a process that Microsoft's security upgrades in turn frequently break! And the need to reinstall Windows often becomes the motivating factor for one to throw away one's computer and start afresh. Worse, to those 99 percent of Windows users who do not maintain proper backups and who store their work at Microsoft's default locations, reinstalling Windows may well mean losing months or years of their work. And all because customers purchased and listened to a Sony CD on their computer?!

James L. Adcock
Bellevue, WA

An Opportunity?

One of the most interesting things about technology is the surprising ways that its various fields influence each other. I was reading the May/June 2006 issue, and a missed opportunity struck me as I finished reading the "Forward" piece on GE's work to drive the hydrogen economy by delivering "a potentially inexpensive, mass-manufacturable version of the technology" for electrolysis of water *("Hydrogen on the Cheap")*, and then flipped a few pages further to find a "Notebook" essay by Professor Schrock regarding his work on producing ammonia *("Nitrogen Fix")*. He writes, "In the presence of protons and electrons in a nonaqueous medium, dinitrogen is reduced to ammonia with an efficiency in electrons of around 65 percent; the remaining electrons are used to make dihydrogen, which is in this context a wasteful and undesirable product." I'm thinking the scientists at GE would find this of great interest; dihydrogen is exactly what they're striving to make. While I'm sure there are difficulties (of, say, transportation and logistics) in using the waste stream from Professor Schrock's work, an industrially viable process to make both ammonia and hydrogen sounds like a winner to me.

Jeff Goldberg
Framingham, MA

Clarification

In the May/June 2006 article "Nanocrystal Displays," Jonathan Steckel was identified as one of the key researchers behind the technology of the featured company, QD Vision. He is also one of the company's founders.

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From The Editor

The Alternative

Catastrophic climate change is not inevitable. We possess the technologies that could forestall global warming. Why can't we use them?

Technology Review is sunnily confident that technology is the single greatest force for expanding human possibilities. But honesty compels us to confess that technology has created the prospect of catastrophic climate change. Technology, too, must provide a solution.

This month, in a package of stories edited by our chief correspondent, David Talbot, we argue that "It's Not Too Late" (the stories begin on page 37). We believe the energy technologies that could forestall the worst effects of global warming *already* exist. Rather than waiting for futuristic alternatives like the much-bruited "hydrogen economy," the nations of the world could begin to control the growth of greenhouse-gas emissions today. What is lacking is any considered strategy.

The problem of anthropogenic climate change is real and urgent. Scientists still debate how quickly and ruinously the climate is changing, but it is now settled fact that our industries are changing the weather. The geological record is clear: atmospheric changes in carbon dioxide, Earth temperature, and sea levels have moved together in predictable formation for 400,000 years. Today, carbon dioxide concentrations are 40 percent higher than at any other time during that period, largely because humans burn oil, gas, and coal. According to Jim Hansen, the director of NASA's Goddard Institute for Space Studies, we are approaching a climacteric: if the concentration of atmospheric carbon dioxide continues to grow at current rates, Earth's temperatures will rise by 2 to 3 °C this century, and sea levels by 15 to 35 meters. Many cities would be destroyed, hundreds of millions of people displaced.

The frightfulness of the threat has suggested what Hansen calls "the Alternative Scenario." Other climate scientists and energy technologists use similar language for similar ideas (including MIT, the owner of *Technology Review*, which announced an energy initiative last year). These alternatives propose to slow or stop the growth in greenhouse gases, even as we develop carbon-free technologies that will satisfy our ever-growing demand for energy. By 2050, these pragmatists propose, we should produce as much as 30 terawatts of power *without* carbon emissions.

The Alternative is, above all, realistic. It accepts that in the short term, at least, we must use the technologies we have rather than those we wish might exist; and it understands that the rich world will *never* voluntarily accept any reduction in its accustomed manner of living, nor will the poor world surrender its legitimate aspirations to wealth.

One example of an existing, potentially clean source of energy is coal, which we examine in "The Dirty Secret," by David Talbot *(p. 52)*. While coal has been the dirtiest of all fuels, spewing more carbon per kilowatt than any other, we could burn it more cleanly by combining the established technologies of gasification, the combined cycle, and carbon dioxide sequestration. U.S. coal companies could start building plants that use these technologies today, but they do not because they have no economic incentive to do so. This is because carbon dioxide emissions are what economists call a "negative externality"—that is, a harm done when the parties to some transaction do not bear its full costs, and a socially undesirable good is overproduced. Put more simply: until carbon dioxide has a cost, it will always be cheaper for coal companies to emit it than to capture it.

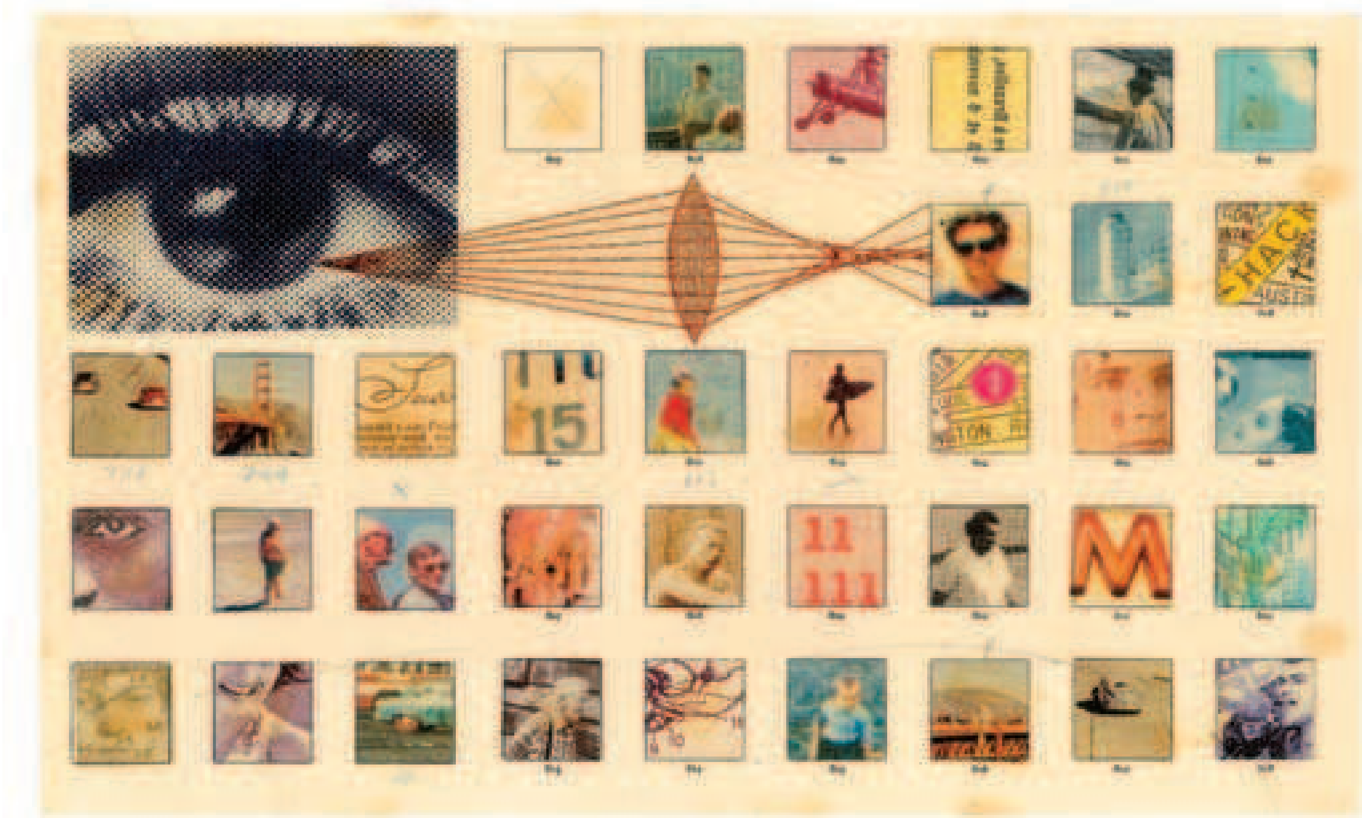
What can we do? Negative externalities can be addressed only by governments, through policies and international agreements. But *what* policies would best support a long-term energy strategy is a topic much debated by environmental economists. Limits on carbon dioxide emissions have disadvantages, even if supplemented with a system for trading emission credits. Such regulations are inflexible and often technologically ill conceived, and they offer energy producers little incentive to reduce emissions below the levels allowed by fiat. So far, they have not worked very well in Europe.

An attractive alternative is a Pigovian tax, where policymakers impose a price on a negative externality. Such a tax would create a cost for carbon dioxide where none existed, and so provide energy producers with an incentive to reduce emissions. Pigovian taxes have been used to reduce pollutants and discourage "sinful" behaviors like smoking, but they have one obvious disadvantage: because there is no exact mechanism for valuing a negative externality, it is possible to tax an undesirable good so much that levels fall *below* what is socially optimal. (We will need carbon-dioxide-emitting energy sources for the foreseeable future.) Still, Pigovian taxes on carbon dioxide emissions would have signal advantages over any alternatives: they would respond to changes in the production costs or price of energy, and they would generate government revenues.

The details of an international energy strategy are all still to be determined. But we have the means to save our civilization. Let us find the way. Write to me at jason.pontin@technologyreview.com. **Jason Pontin**

Forward

TECHNOLOGY REVIEW JULY/AUGUST 2006



MARTIN O'NEILL

BIOENGINEERING

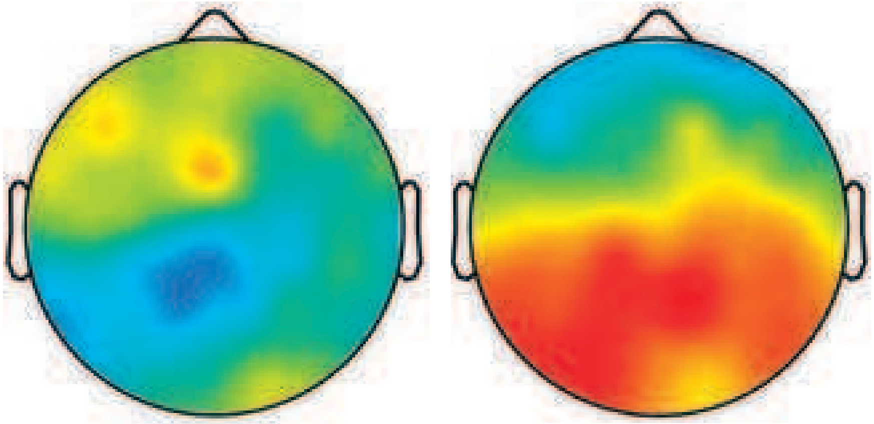
Subliminal Search

A brain monitor could vastly improve image analysts' efficiency

The number of images recorded by security cameras each day vastly exceeds human analysts' ability to examine them. "Computer vision" systems aren't much help: they're still far too primitive to tell a prowler from a postman. But researchers say the human brain can subconsciously register an anomaly in a scene—say, a shadow where there shouldn't be one—much faster than a person can visually and verbally identify it. If computers could somehow monitor the brain and flag these "aha" moments, surveillance analysts might be able to scan many times more images per hour.

That's what Paul Sajda, a bioengineer at Columbia University's Laboratory for Intelligent Imaging and Neural Computing, hopes to enable with his "cortically coupled computer vision" system, or "C3Vision." Sajda's prototype, built with a grant from the U.S. Defense Advanced Research Projects Agency, includes a bonnet of electrodes that is placed on a subject's head, where it monitors changes in the brain's electrical activity. A computer scrutinizes those changes for the neural signatures of interesting events and images, as the subject watches a video running at 10 times its normal speed. The flagged images are picked out for a more intensive examination.

"We are aiming to speed up [visual] search by 300 percent," says Sajda. "The system is designed not only for finding very specific targets but also things image analysts think are 'unusual,' which is very difficult to do with a computer vision system."



Top-down views of electroencephalogram readings show the distinctive neural "signatures" produced when a subject views an uninteresting image (left) and a target image (right).

Such devices could help law enforcement or counterterrorism officials spot signs of suspicious activity that would otherwise slip by as they scanned surveillance images. "Any system that can help process those images and prioritize them as to likelihood of containing important data is a vast improvement over the current situation," says Leif Finkel, a professor of bioengineering at the University of Pennsylvania, who was Sajda's doctoral thesis advisor.

Outside the security realm, radiologists hooked up to the C3Vision system could quickly screen hundreds of mammograms to identify those requiring a closer look, and photo researchers could use it to single out pictures of a particular person among the millions of photographs on the Web. "People are amazingly accurate at identifying whether a particular image—say, of Marilyn Monroe, or the Washington Monument—was presented as one photo" in a series of hundreds, even at a speed of 10 to 20 images per second, says Finkel.

According to Sajda's recent tests, subjects spotted 90 percent of the "suspicious" images in a series running at 10 images per second.

"I think that it is too early to tell whether this particular approach is going to work in real applications," says Misha Pavel, a professor of biomedical engineering at Oregon Health Sciences University. "But I have no doubt that we will learn from this approach, and the consequences may be entirely unexpected, novel applications." **LAKSHMI SANDHANA**

DIAGNOSTICS

Nano Test for Heart Attacks

Every year, thousands of heart attack victims are sent home without treatment by emergency-room doctors because tests don't show clear signs of a problem, such as elevated levels of proteins released into the blood by dying heart cells. But an ultrasensitive detector, expected to be widely available for clinical evaluation later this year, could save lives by recognizing those proteins at a thousandth the concentration that current methods can detect—or even less. The device, built by Nanosphere of Northbrook, IL, is based on research by Northwestern University chemist Chad Mirkin, who developed a way to coat gold nanoparticles with selectively "sticky" substances, such as DNA strands constructed to bind with complementary target DNA in a sample. When the nanoparticles, stuck to their targets, attach to a microarray that also bears complementary DNA, a digital camera can scan them to find the sample's DNA concentration. A similar method, using antibodies as the glue, can measure protein concentrations.

Clinical trials are now testing techniques that could be used to diagnose previously undetected heart disease and Alzheimer's disease. Nanosphere's CEO, Bill Moffitt, says the device could reveal levels of telltale Alzheimer's proteins in the blood at concentrations "undetectable by any other technology." **KEVIN BULLIS**

Nanosphere's device detects proteins in minute quantities.

COURTESY OF PAUL SAJDA (EEG); COURTESY OF NANOSPHERE (NANO TEST)

Wind turbines off Ireland's coast produce 3.6 megawatts of electricity each.

ENERGY

Floating Wind Farms

Even some energy-conscious Massachusetts residents oppose a plan to put dozens of electricity-generating wind turbines on towers about eight kilometers off the southern coast of Cape Cod, saying they would be an eyesore. But huge turbines in development at General Electric could make battles with coastal residents a thing of the past. Researchers say the turbines could be placed on floating platforms, far at sea and invisible from the shore.

In March, GE announced a $27 million partnership with the U.S. Department of Energy to develop 5- to 7-megawatt turbines by 2009, supplanting the company's current 3.6-megawatt turbines. Each of these giant energy factories, with rotors 140 meters in diameter, would produce enough electricity to power up to 1,750 homes—and at a more economical rate than smaller turbines, since the cost of building offshore wind farms depends more on the number of turbines than on their size.

Meanwhile, a group of MIT researchers led by Paul Sclavounos, a professor of mechanical engineering and naval architecture, have demonstrated the feasibility of placing such turbines atop large floating cylinders ballasted with concrete and anchored to the seafloor by cables. With this design, wind farms could be located in water ranging from 30 meters deep to 300—far out on the continental shelf, where they not only would be invisible from shore but also would catch more wind. **KEVIN BULLIS**

INFOTECH

Virtual Contractors

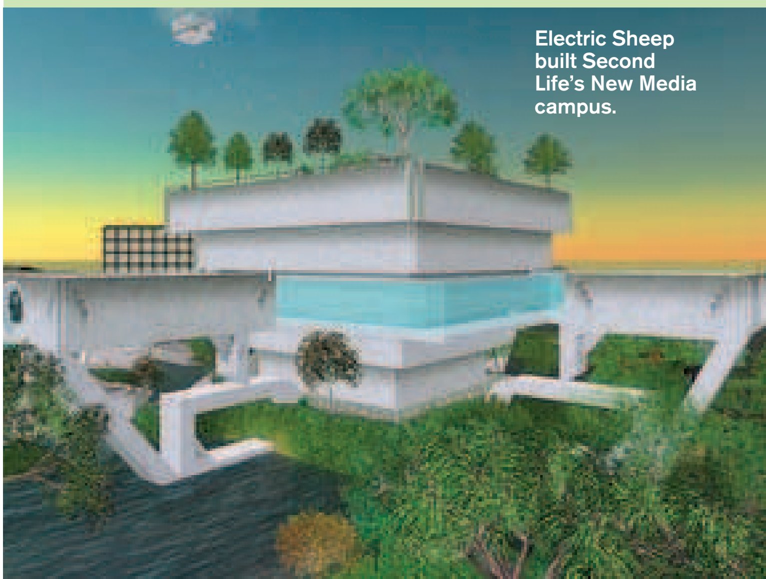
Fully navigable online worlds are flourishing, and all that virtual real estate needs to be furnished. Fantasy worlds such as Linden Labs' Second Life and even reality-based environments such as Google Earth are built to accommodate user-generated houses and other objects, which anyone can design using in-game tools or Google's SketchUp 3-D modeling software. But if you want a modernist masterpiece on your plot of virtual land, you don't have to build it yourself. Several companies and hundreds of individuals have gone into business as virtual contractors, designing items and structures that they can sell for real-world cash.

The group most fully integrated into Second Life is Electric Sheep of Washington, DC, whose 11 designers and developers can build anything from a stately pleasure dome to an entire interactive island. For the New Media Consortium, a not-for-profit group of more than 200 teaching organizations with a focus on new media technologies, the company designed and built such an island, where the consortium held virtual classes and events attended by the digital "avatars" of people around the world.

Electric Sheep declined to discuss the fees it charges for original designs. But the company also runs SLBoutique.com, where citizens of Second Life spend about $20,000 a month buying other members' digital creations, from skyscrapers to body parts, according to the company's CEO, T. Sibley Verbek.

The 3-D environment of Google Earth isn't shared or interactive like Second Life—but users can still customize their virtual experiences. Google's 3D Warehouse lists user-submitted models of real-world structures such as the Taj Mahal, which users can download into their copies of Google Earth. Enthusiasts can create new models using the free version of SketchUp or a $495 "pro" edition that offers animations and walkthroughs.

Though Google Earth models aren't bought and sold, Brad Schell, product director for SketchUp and the 3D Warehouse, suggests that corporations could one day create virtual versions of their stores—which could then be placed into Google Earth, perhaps allowing users to roam virtual aisles for products they could order online. **DANIEL TURNER**



Electric Sheep built Second Life's New Media campus.

COURTESY OF ELECTRIC SHEEP (CONTRACTORS); COURTESY OF GE (WIND)

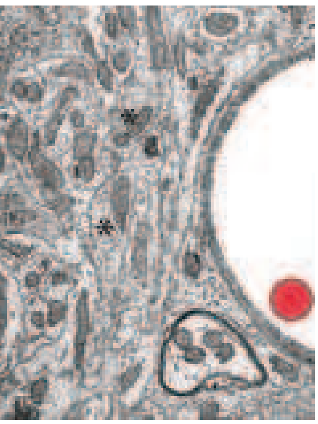
Forward

NANOTECHNOLOGY

Nanowires in the Brain

To treat severe cases of Parkinson's disease, surgeons implant electrodes deep in the brain, where they deliver high-frequency electrical pulses that shut down neural systems responsible for the disease's characteristic tremors. But this expensive treatment, called deep brain stimulation, is risky: the patient's skull must be opened, and the electrodes can damage blood vessels in the brain.

A new type of polymer nanoelectrode, however, could make brain implants far safer and less costly. Rodolfo Llinas, a professor of neuroscience at New York University, has worked with Ian Hunter, a professor of mechanical and biological engineering at MIT, to develop a nanowire electrode just 600 nanometers across—so thin that it could be inserted through an artery in the arm or groin, threaded up to the brain, and snaked through the smallest blood vessels, getting close enough to neurons to detect and deliver electrical signals.



NYU's electrode (represented in red) fits through tiny capillaries.

Before the technology can be used in humans, the researchers will have to demonstrate that the nanowires do not cause complications, such as blood clots. But Joseph Pancrazio, a program director at the National Institute of Neurological Disorders and Stroke, says, "There may be payoffs in terms of safety, efficacy, robustness, and biocompatibility.…This is a completely out-of-the-box way to think about enabling deep brain stimulation." KEVIN BULLIS

COMMUNICATIONS

Multilingual Mobile Messenger

"Giant waves coming, rush 1,000 meters away from the beach." These 10 words, if sent to mobile phones in the Bahasa, Malay, Sinhala, Tamil, and Telugu languages, might have saved thousands of people from the Indian Ocean tsunami of 2004. But even if South Asia had had a tsunami detection system in place—which it didn't—authorities would have had little chance of distributing such a message, given the variety of languages and writing systems used in the region.

Now, Geneva Software Technologies in Bangalore, India, has developed software that will translate English text messages into multiple languages and send a translation to any cellular phone or mobile device in the world, no matter what character set it's programmed to use. India's Ministry of Science and Technology announced in February that it intends to use Geneva's system to deliver disaster alerts.

Existing text-messaging technology requires that both sender and receiver have devices that use Unicode, the standard international system for representing characters on a digital screen. But in rural areas of developing countries, few people can afford Unicode-compliant handsets.

The system Geneva devised can display characters from 14 Indian languages—and 57 others used around the world—without the need for common standards. Instead, language characters are transmitted as pictures encoded in simple binary format, which almost any phone can render on-screen. Messages can be targeted to specific regions using the cellular networks' databases of phone subscribers' preferred languages.

"With our technology, a message in any language can be sent to any mobile as long as it supports picture messaging," says Vinjamuri Ravindra, an electrical engineer and R&D director with Geneva.

The multilingual messaging software is compatible with most types of cell phones used in Asia and is compact enough to be stored on a subscriber identity module (SIM) card. "This is an example of how information technology could make a big difference in disaster warning," says former Indian science and technology secretary Valangiman Ramamurthy, whose department contributed $880,000 to the product's development.

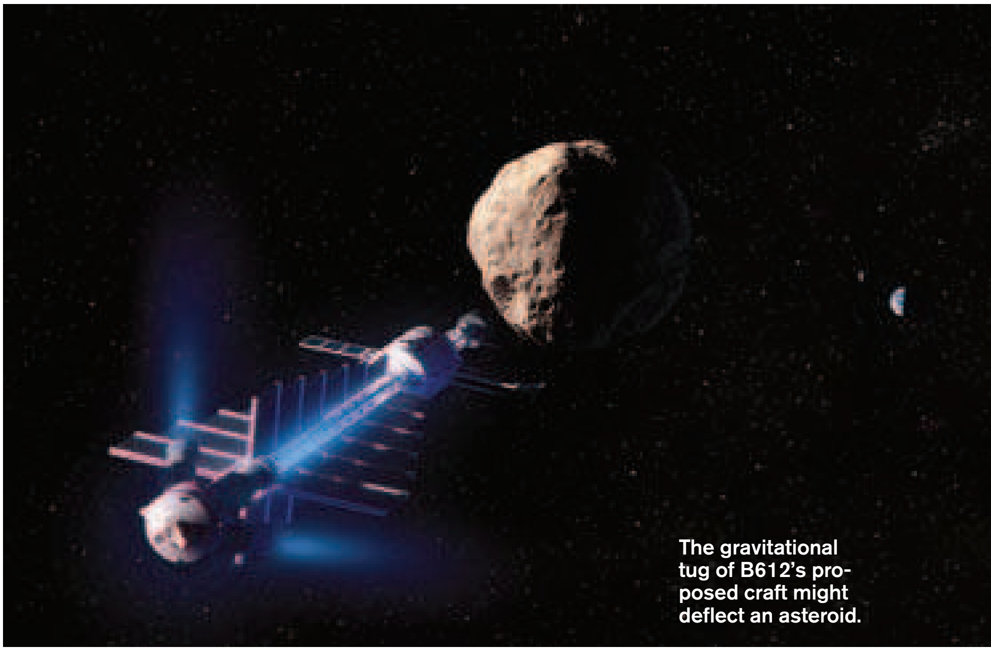
Like all computer-rendered translations, Geneva's vary in accuracy, depending in part on their sources' subjects and contexts. But the company has been working with the Indian Meteorological Department to create standard templates that should minimize this problem in disaster alerts. GANAPATI MUDUR

KEN ORVIDAS (MESSENGER); COURTESY OF RODOLFO LLINAS (NANOWIRES)

SPACE

Gravity Tractor

How to lasso wayward asteroids



The gravitational tug of B612's proposed craft might deflect an asteroid.

Sooner or later, say astronomers, an asteroid will be discovered on a collision course with Earth. Humanity will then begin all-out planning to prevent an impact. But while there are already plenty of ideas about how to shove asteroids out of Earth's way, nobody knows whether any of them would work.

To change that, two groups in the United States and Europe have been developing separate plans for robotic missions to visit nonthreatening asteroids, try to deflect their orbits, and watch how they respond. One group is the private B612 Foundation of Tiburon, CA, which aims to launch an unmanned spacecraft sometime in the next decade to try out a new idea for diverting an asteroid without even touching it. If a spacecraft flew to an asteroid decades before its expected impact and hovered there for years—the required period would vary according to the masses of the spacecraft and the asteroid—the slight gravitational pull of the spacecraft itself might change the asteroid's orbit enough to turn a hit into a miss, according to a study published last November in the journal *Nature* by NASA astronauts Stanley Love and Edward Lu, who is a member of the board of B612. They call the concept the "gravity tractor."

The tractor could deflect an asteroid before it passes through a "keyhole," an imaginary hoop in space through which asteroids must pass if they are to strike Earth; bypassing such a keyhole would ensure a miss. Influencing an asteroid without touching it could be an advantage, since some asteroids are thought to be loosely bound piles of rubble that could simply fall apart under the influence of a more direct push, such as a nuclear detonation.

At the same time, the European Space Agency has been planning a mission called Don Quijote, which would send two robot craft to intercept an asteroid. One would crash into it, perhaps nudging it aside, while the other would fly nearby to observe the results.

In May, the B612 researchers and the European agency began "exploratory discussions" about combining the two concepts into one cheaper mission, testing first the no-touch method and then the impact, says Rusty Schweickart, a former Apollo astronaut and one of the founders of B612. **DAVID L. CHANDLER**

GENETICS

Why Mice Drink

Most scientists believe that alcoholism is a genetic disease linked to differences in the way the genes in different people's brain cells regulate the chemical pathways affected by alcohol. But they've had little success determining exactly which pathways and genes are critical, partly because alcohol affects so many brain functions.

Now, with the help of advanced DNA microarray technology, studies of alcohol-preferring lab mice are narrowing down the possibilities. In a study led by Susan Bergeson, a neurobiologist at the University of Texas at Austin, researchers compared gene expression in the brains of two groups of mice, one averse to alcohol and the other preferring a 10 percent ethanol solution in their water bottles. Using high-throughput microarrays, which can measure the expression levels of thousands of genes at once, Bergeson's team found 3,800 genes that seemed to be associated with how much the mice liked alcohol; 36 in that group were labeled high priority, as similar genes are found in stretches of the human genome that have been implicated in alcoholism.

Future research may examine these genes using databases of DNA samples from alcoholics and their family members—work that could eventually help doctors screen patients for a genetic predisposition to alcoholism.

KATHERINE BOURZAC

DAN DURDA—FIAAA/B612 FOUNDATION

ENERGY

Rocky Start for CO_2 Trading

In 2002, the European Union ratified the 1997 Kyoto Protocol on climate change, which requires that global greenhouse-gas emissions be reduced by 2012 to an amount 5 percent below 1990 levels. To do its part, the EU is relying largely on market mechanisms. Companies that operate certain carbon-emitting facilities, such as coal- or oil-fired electrical generating stations, are granted "allowances"—the legal right to release a certain amount of carbon dioxide into the atmosphere each year—and may buy and sell these allowances as they wish.

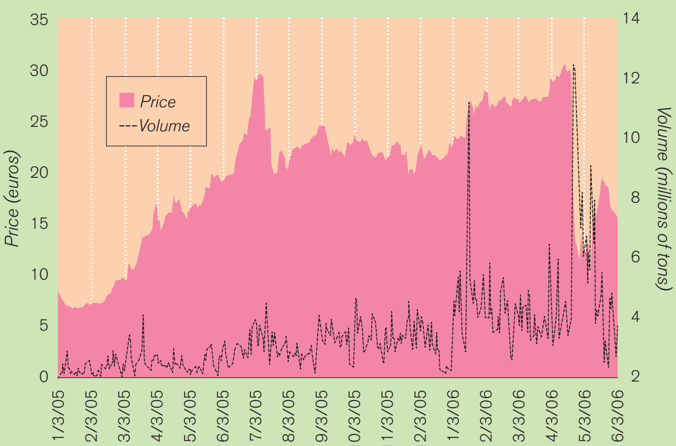
Such a market, in theory, gives companies an incentive to reduce emissions, so that they can avoid buying extra allowances and sell their surplus ones. But the European Union Greenhouse Gas Emissions Trading Scheme, which opened in January 2005, has already run into some unexpected glitches. In April and May, data leaked by some member states and the European Commission showed that in the first year of the market's operation, most EU countries handed out more allowances than were needed. Total allowances exceeded the actual amount of carbon emitted by at least 67 million tons, or 3.4 percent, according to PointCarbon, a research firm based in Oslo, Norway. The news disoriented carbon traders and caused allowance prices, which had risen steadily since the market's opening, to plummet from about 30 euros per ton of carbon dioxide to a low of less than 10 euros per ton.

Low allowance prices mean companies have little incentive to reduce their emissions. Governments have been so generous when allocating permits that this first, experimental phase of allowance trading—which lasts through 2007—is unlikely to lead to real emissions reductions, says Christian Azar, a professor of physical-resource theory at Chalmers University in Gothenburg, Sweden. What's needed, says Azar, is a cap on allowances.

PATRIC HADENIUS

Pollution's Price

The value of European CO_2 allowances tumbled in April.



Source: PointCarbon

COMPUTING

1,000 Cores on a Chip

Rapport's Kilocore chip makes quick work of video processing

Today's hottest microprocessors for consumer PCs, Intel's Core Duo and AMD's Athlon 64 X2, combine two central processing units—or "cores"—on a single chip, where they can divide up tough jobs like encrypting data or processing high-definition video. Intel and AMD have begun to talk about "quad core" chips and even eight-core devices, which might be on the market by 2008. But in Redwood City, CA, there's a small company called Rapport that's already working on a 1,000-core chip.

Called the Kilocore1025 and expected to ship in mid-2007, the chip is designed to power handheld devices like game and media players. It includes an IBM Power PC CPU for general-purpose tasks but a whopping 1,024 additional "processing elements." Each element handles only eight bits of data at a time, in contrast to 32 or 64 bits for today's leading processors, and runs at the relatively low clock speed of 100 megahertz, far slower than the two to three gigahertz of today's notebook and desktop PCs. But that means the Kilocore chip consumes only one-tenth as much power as Intel's latest notebook PC chips.

Rapport's debut chip, available later this year, has 256 processing elements.

And while the Kilocore's individual cores run slowly, they can work in parallel to churn quickly through tasks like streaming video, says Fred Furtek, a lead chip architect for Rapport. That should translate into smooth video without the chops and hiccups that occur when your cell phone or PC can't keep up with a video clip.

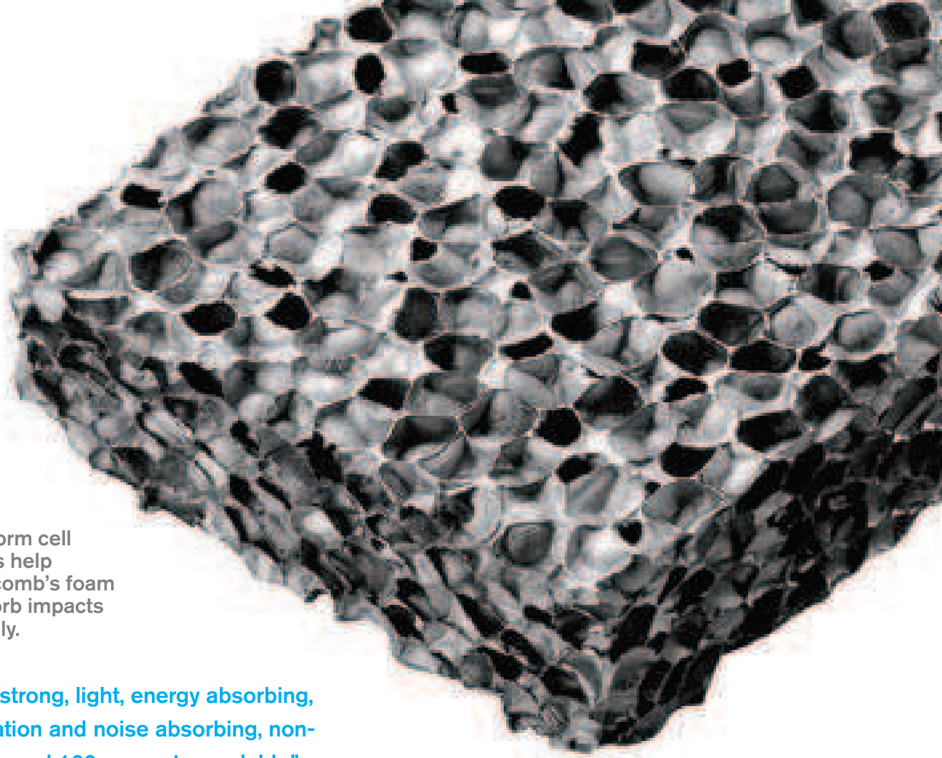
A debut chip with 256 processing elements will ship later this year. But before Rapport's chips can go into next-generation mobile devices, the company must improve the software-development tools that let programmers take advantage of Kilocore's parallel-processing architecture. "The graphics problem is wonderfully dividable," says PC industry veteran Roger Kay, president of market research firm Endpoint Associates—so it's relatively easy to handle with parallel processors. But without the right development tools, Kay says, Rapport will have difficulty selling its ideas to device makers.

LAURIANNE MCLAUGHLIN

COURTESY OF RAPPORT

MATERIALS

Aluminum Foam



Uniform cell sizes help Metcomb's foam absorb impacts evenly.

When a speeding object strikes a piece of plastic foam such as polystyrene, the work required to crush the walls of the millions of air cells in the foam slows the object down. That's why polystyrene is ideal for use in bicycle helmets and other protective gear. Metals such as aluminum can also form foams—and because of their greater rigidity, they could, in theory, dissipate as much energy as a polymer foam in a much thinner layer. In practice, however, it's been impossible to manufacture metal foams with the uniform cell sizes needed to spread out an impact evenly.

Now an Austrian company has developed a way to make aluminum foam with evenly sized cells, potentially opening the way to safer automobiles with metal-foam parts such as door side-impact beams. "Cellular aluminum has a number of advantages that no other metal has," says Gerald Högl, CEO of Schwarzenau-based Metcomb Nanostructures. "It's strong, light, energy absorbing, vibration and noise absorbing, nontoxic, and 100 percent recyclable."

Metcomb's engineers keep the cells in their foam uniform by adjusting the nanoscale oxide layer on the cell surface and by adding small-scale particles to molten aluminum, which controls its viscosity and hence the size of the bubbles that form inside it. Engineer Jörg Wellnitz, vice dean at the University of Applied Sciences in Ingolstadt, Germany, and a member of Metcomb's scientific advisory board, will use Metcomb's foam to try to develop impact-absorbing car doors and armor for vehicles and buildings. "Due to the fact that we can go from cell sizes of about two millimeters up to twelve or more, we can finely adjust the foam's impact-absorbent properties," says Wellnitz, who believes the material's first commercial application will be to protect against terrorist blasts. WADE ROUSH

DEFENSE

War Games

In Iraq and other conflict zones with unfamiliar cultures, U.S. soldiers can find it hard to identify threats and targets amid the hubbub of everyday life. Yet their interactions with locals yield far more information than intelligence officers could collect on their own—hence the emerging military doctrine that "every soldier is a sensor."

Now the U.S. Army Research and Development Command's Simulation and Training Technology Center in Orlando, FL, has translated that doctrine into a video game. The purpose: to help soldiers learn to recognize signs of danger or opportunity in the field. Teaching through video games is nothing new for the army. Full Spectrum Warrior, a "first-person shooter" for PCs and video game consoles, was originally developed as an army training aid. But the Every Soldier a Sensor Simulation (ES3) is heavier on social skills than on combat. "In our environment of asymmetric warfare, you're trying to win the hearts and minds of people," says Lieutenant Colonel Raymond Compton, director of military operations at the Orlando center. "The last thing you want to do is to pull your trigger."

Soldiers inspect a car in ES3's virtual Iraq.

Like many commercial games, ES3 unfolds from a first-person point of view, with the player assigned a mission—searching for a hidden bomb, for example. But an ES3 player must simultaneously maintain a rapport with the locals. Players are evaluated on how well they gather and report information.

ES3 runs on almost any computer and can be customized by soldiers themselves. It comes with a built-in editing program that allows soldiers to upload digital photos of real-life details—say, an undocumented style of Iraqi dress—to the army's online ES3 network. If administrators approve these additions, they are incorporated into future play.

In the coming months, ES3 will be modified to include a sort of built-in language trainer, which will familiarize soldiers with common Iraqi phrases and symbols. "These aren't games," says Compton. "They're a new type of digital training."

DAVID KUSHNER

COURTESY OF THE U.S. ARMY SIMULATION TRAINING AND TECHNOLOGY CENTER (GAME); COURTESY OF METCOMB NANOSTRUCTURES (FOAM)


How the Doughboy graces millions of dinner tables. Always in a timely fashion.
Each day, Pillsbury products and other General Mills brands appear in millions of shopping carts around the world. HP Integrity servers with Intel® Itanium® 2 processors help keep distribution and inventory control systems running smoothly. "With their continuous performance and support, we are able to ensure that customer orders and shipments are processed quickly and accurately," said Vandy Johnson, Director of I.S. Operations. "And that's a comforting thought." itanium-integrity.com
ITANIUM + INTEGRITY. ON AND ON AND ON.
intel

Lego Mindstorms NXT

The company known for the simplest of building toys has created a simple robotics platform.

By Daniel Turner

The Software

The NXT kit comes with control and programming software based on LabView from National Instruments. An icon-based drag-and-drop environment makes it easy to program robotic creations. Users might start by telling a robot to turn left if it encounters an object; from there, they can build up if-then branches to elicit more sophisticated behavior. The software also includes programming instructions for sample projects.

A The NXT Brick

The base of the Mindstorms NXT system contains a microprocessor, four sensor ports, three motor ports, a USB 2.0 port for downloading programs, a speaker, control buttons, and an LCD screen. The motor ports send control signals to the motors and receive feedback from them—recording how many rotations they've made, for example. The LCD screen can be configured to display information from the sensors, or commands, or text messages sent to the brick. The buttons used for navigating menus on the screen can also be configured as touch sensors, in case you want your creation to be able to detect when the brick comes in contact with something.

B Servo Motors

With the first generation of Mindstorms kits, it was hard to build bots that would travel in a straight line; one of the wheel-mounted motors might be slightly stronger than the others. Some hobbyists worked around this problem by adjusting the wheels manually or designing their own rotation sensors. The NXT motors, however, have built-in rotation sensors. A tachometer measures the speed of the motor and produces a voltage proportional to that speed. That voltage is compared with a reference voltage corresponding to the speed the programmer has set for the robot; the motor's speed is then automatically adjusted. The sensors can also measure how far each wheel has turned, allowing for precise turning commands.

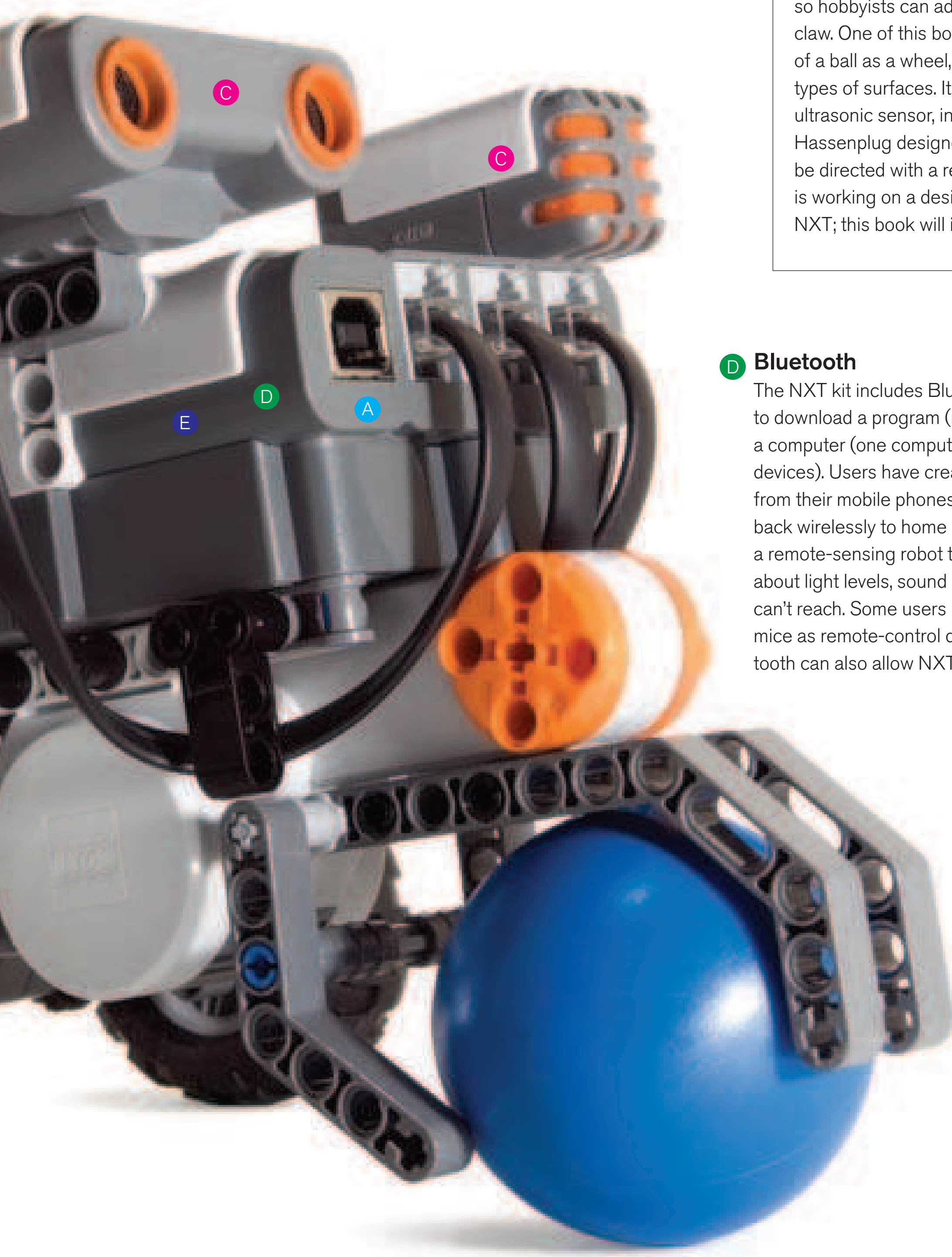
CHRISTOPHER HARTING

Sensors

The touch sensor *(not shown)* can accommodate an axle that can extend the length of a bumper, which triggers the sensor when it hits an object. The light sensor *(not shown)* is more sensitive than the previous version. The sound sensor, which is new to NXT, can measure sound levels, so that the same command given softly or loudly can elicit a different response. Also new is the ultrasonic sensor, which allows a robot to judge its distance from objects by sending out a signal and tracking how long it takes to return.

The Story behind NXT

In 1998, Lego introduced the Mindstorms Robotic Invention System, which became popular with robotics hobbyists and educators. The 519-piece Mindstorms NXT kit, available in August, was devised in secret with the help of 100 developers. "Mouse" *(pictured)* was created by one of them: Steven Hassenplug, a 40-year-old software engineer who has been playing with Legos for over 30 years. Hassenplug designed Mouse as a base robotics platform; it includes an extra motor attachment so hobbyists can add their own devices, such as a claw. One of this bot's outstanding features is the use of a ball as a wheel, allowing it to move on different types of surfaces. It also uses the Mindstorms NXT ultrasonic sensor, in conjunction with the programming Hassenplug designed for it, to avoid objects—and can be directed with a remote control *(far left)*. Hassenplug is working on a design book about Mindstorms NXT; this book will include plans for Mouse.



Bluetooth

The NXT kit includes Bluetooth technology, allowing users to download a program (read: personality) wirelessly from a computer (one computer can also control multiple NXT devices). Users have created programs for doing the same from their mobile phones. NXT projects can also send data back wirelessly to home base. That means you can make a remote-sensing robot that can deliver data—information about light levels, sound levels, and so on—about places you can't reach. Some users have even set up Bluetooth-enabled mice as remote-control devices for their NXT projects. Bluetooth can also allow NXT devices to "talk" to each other.

Microprocessor

The brain of the NXT kit is a low-power 32-bit microprocessor, a significant step up from the 8-bit CPU of the previous Mindstorms generation. This year, Lego announced that it will release the chip's firmware as open-source software, which will allow users to delve deeper into the logic of robotics and customize their NXT projects even more.

Seth Lloyd

Hacking the universe

Seth Lloyd, a professor of mechanical engineering at MIT, is among the pioneers of quantum computing: he proposed the first technologically feasible design for a quantum computer. If humans ever build a useful, general-purpose quantum computer, it will owe much to Lloyd. Earlier this year, he published a popular introduction to quantum theory and computing, titled *Programming the Universe*, which advanced the startling thesis that the universe is *itself* a quantum computer.

TR: In your new book, you are admirably explicit: you write, "The Universe is *indistinguishable* from a quantum computer." How can that be true?

Lloyd: I know it sounds crazy. I feel apologetic when I say it. And people who have reviewed the book take it as a metaphor. But it's factually the case. We couldn't build quantum computers unless the universe were quantum *and* computing. We can build such machines because the universe is storing and processing information in the quantum realm. When we build quantum computers, we're hijacking that underlying computation in order to make it do things we want: little and/or/not calculations. We're hacking into the universe.

Your critics can be forgiven for thinking you wrote metaphorically. In every era, scientists have likened the universe to the most complicated technology they knew. Newton thought the universe was like a clock.

You could be more blunt: "Lloyd builds quantum computers; therefore, Lloyd thinks the universe is a quantum computer." But I think that's unfair.

You famously believe in "it from bit": that is, that information is a physical property of the universe, and that information generates more-complex information—and with it, all the phenomenal world.

Imagine the electron, which an ordinary computer uses to store data. How can it have information associated with it? The electron can be either here or there. So it registers a bit of information, one of two possibilities: on or off.

Sure, but how does the quantity of information *increase*?

If you're looking for places where the laws of physics allow for information to be injected into the universe, then you must look to quantum mechanics. Quantum mechanics has a process called "decoherence"—which takes place during measurement, for instance. A qubit [or quantum bit] that was, weirdly, both here *and* there is suddenly here *or* there. Information has been added to the universe.

And why does the universe tend to complexity?

This notion of the universe as a giant quantum computer gets you something new and important that you don't get from the ordinary laws of physics. If you look back 13.8 billion years to the beginning of the universe, the Initial State was extremely simple, only requiring a few bits to describe. But I see on your table an intricate, very beautiful orchid—where the *heck* did all that complex information come from? The laws of physics are silent on this issue. They have no explanation. They do not encode some yearning for complexity.

***[Utterly bemused]* Hmmm ...**

Could the universe have arisen from total randomness? No. If we imagine that every elementary particle was a monkey typing since time began at the maximum speed allowed by the laws of physics, the longest stretch of *Hamlet* that could have been generated is something like "To be or not to be, that is the—." But imagine monkeys typing at *computers* that recognize the random gibberish as a program. Algorithmic information theory shows that there are short, random-looking programs that can cause a computer to write down all the laws of physics. So for the universe to be complex, you need random generation, and you need something to process that information according to a few simple rules: in other words, a quantum computer.

More practically: how far are we from widely used, commercial applications of quantum computing?

Today, the largest general-purpose quantum computer is only a dozen bits. So we're at least a decade or two away. But we've already built quantum computers that simulate other quantum systems: you could call them quantum *analog* computers. These little machines can perform computations that would require an ordinary computer larger than the universe.

What's the next big thing that needs to be done in quantum computing?

From the techno-geek, experimentalist point of view, it's the pacification of the microscopic, quantum world. It's the Wild West down there.

***Programming the Universe* concludes with a personal note. You describe how your friend Heinz Pagels, a renowned physicist, fell to his death while hiking with you in Colorado. You find some consolation in your theory of universal quantum computation: "But we have not entirely lost him. While he lived, Heinz programmed his own piece of the universe. The resulting computation unfolds in us and around us ..."**

Well, it's pretty poor consolation when someone you love is dead. But it's a truer consolation than the idea that one day you might meet him in heaven.

JASON PONTIN

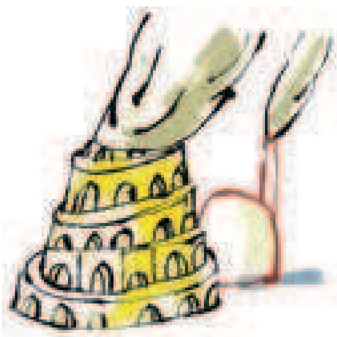
ED QUINN

ENERGY

DOE's Blurred Nuclear Vision

A consistent strategy, says **Andrew C. Kadak**, is the key to a successful nuclear future.

In the mid-1990s, many people were ready to write off the nuclear industry. Nuclear power plants were being shut down as troublesome and uneconomical. Four of the nine plants operating in New England closed; as CEO of Yankee Atomic Electric Company, I presided over the closure of the Yankee Rowe plant in western Massachusetts. Neglect in Washington, across several administrations, contributed to this state of affairs. Under President Clinton, support for nuclear-engineering programs was cut for several years.



But while the future of nuclear power was apparently dimming, nuclear utilities improved operations and made money with existing plants. And then the Clinton administration began to quietly renew funding for nuclear research. This resurgence of support was largely driven by global-warming concerns. Although no one was seriously considering opening new nuclear plants in the near term, the U.S. Department of Energy began examining what technologies would be needed in the next 20 to 30 years.

The resulting Generation IV Nuclear Initiative was launched in 2000. An international team identified a need for near-term solutions, so the DOE then established "Nuclear Power 2010" to help make new plants operational by that year.

In 2003, the department announced the Advanced Fuel Cycle Initiative to find better ways of processing and utilizing nuclear waste. But the department's new initiatives kept coming. The Next Generation Nuclear Plant (NGNP) project was supposed to demonstrate not only electricity generation but also hydrogen production, as part of President Bush's Hydrogen Fuel Initiative. This year, the DOE unveiled the latest in its series of initiatives: the Global Nuclear Energy Partnership (or GNEP; see "The Best Nuclear Option" on page 58), a plan for reprocessing spent nuclear fuel while preventing proliferation.

Each of these initiatives redirected DOE labs to new missions they lacked the funding to fulfill. The national labs struggled to keep up. Universities saw projects dropped. Programs that were beginning to make progress were canceled or put on hold.

And one can only imagine the impact on established programs at the national labs. Once a program is stopped, restarting it becomes difficult; once money is diverted, it is hard to get back.

The DOE has changed direction so many times in such a short period that it is in danger of going nowhere. What should it do? Given finite resources, focus on the top priorities. Without a nuclear renaissance—which means real orders for new plants—there will be less need for GNEP's novel solution to the waste problem. The department should spend resources to ensure that a renaissance actually occurs. In other words, help with engineering, to lessen the high initial costs. Do not discourage and confuse the utilities; instead, ensure that a repository will be in place to handle nuclear waste, in whatever form it takes. Establish a strategy for deploying the next generation of nuclear plants.

Finally, conduct the necessary research before choosing technologies for reducing the volume and radioactivity of spent fuel, as MIT's 2003 study "The Future of Nuclear Power" recommended. And above all, stay on one course long enough for limited resources to be spent wisely—and not wasted by more changes in direction. TR

Andrew C. Kadak is Professor of the Practice in the Department of Nuclear Science and Engineering at MIT.

INFORMATION TECHNOLOGY

Technology Design or Evolution?

Steve Jurvetson believes that the two processes for building complex systems are fundamentally different.

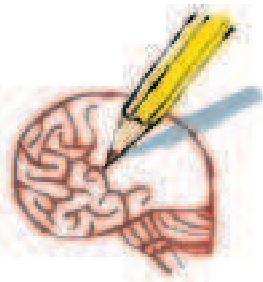
Many of the most interesting problems in computer science, nanotechnology, and synthetic biology require the construction of complex systems. But how would we build a really complex system—such as a general artificial intelligence (AI) that exceeded human intelligence?

Some technologists advocate design; others prefer evolutionary search algorithms. Still others would conflate the two, hoping to incorporate the best of both while avoiding their limitations. But while both processes are powerful, they are very different and not easily combined. Rather, they present divergent paths.

Designed systems offer predictability, efficiency, and control. Their subsystems are easily understood, which allows their reuse in different contexts. But designed systems also tend to break easily, and they have conquered only simple problems so far. Compare, for example, Microsoft code and biological code: Word is larger than the human genome.

By contrast, evolved systems demonstrate that simple, iterative algo-

ILLUSTRATIONS BY ERIC HANSEN



rithms, distributed over time and space, can accumulate design and create complexity that is robust, resilient, and well adapted to its environment. In fact, biological evolution provides the only "existence proof" that an algorithm can produce complexity transcending that of its antecedents. Biological evolution is so inspiring that engineers have mimicked its operations in areas such as genetic programming, artificial life, and the iterative training of neural networks.

But evolved systems have their disadvantages. For one, they suffer from "subsystem inscrutability." That is, when we direct the evolution of a system, we may know how the evolutionary process works, but we will not necessarily understand how the resulting system works internally. For example, when the computer scientist Danny Hillis evolved a simple sort algorithm, the process produced inscrutable and mysterious code that did a good job at sorting numbers. But had he taken the time to reverse-engineer his system, the effort would not have provided much generalized insight into evolved artifacts.

Why is this? Stephen Wolfram's theory of computational equivalence suggests that simple, formulaic shortcuts for understanding evolution may *never* be discovered. We can only run the iterative algorithm forward to see the results, and the various computational steps cannot be skipped.

Thus, if we evolve a complex system, it is a black box defined by its interfaces. We cannot easily apply our design intuition to the improvement of its inner workings. We can't even partition its subsystems without a serious effort at reverse-engineering. And until we can understand the interfaces between partitions, we can't hope to transfer a subsystem from one evolved complex system to another.

A grand engineering challenge therefore remains: can we integrate the evolutionary and design paths to exploit the best of both? Can we transcend human intelligence with an evolutionary algorithm yet maintain an element of control?

The answer is not yet clear. If we artificially evolve a smart AI, it will be an alien intelligence defined by its sensory interfaces, and understanding its inner workings may require as much effort as we are now expending to explain the human brain.

Humans are not the end point of evolution. We are inserting ourselves into the evolutionary process. The next step in the evolutionary hierarchy of abstractions will accelerate the evolution of evolvability itself. TR

Steve Jurvetson is managing director of the venture capital firm Draper Fisher Jurvetson.

BIOTECHNOLOGY

Engineering Biology

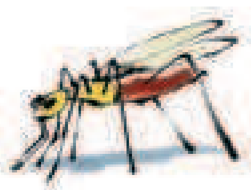
The time is now for developing biology into a full-fledged engineering field, says bioengineer **Jay Keasling**.

Synthetic biology seeks to design and construct biological components that can be modeled, understood, tuned to meet specific criteria, and assembled into larger integrated systems that solve specific problems. Such capabilities could transform biology in the way that integrated-circuit design transformed computing. Researchers could redesign enzymes, genetic circuits, and cells to their specifications, or even build biological systems from scratch.

Scientists have already made significant strides toward engineering microörganisms that produce ethanol, bulk chemicals, and drugs from inexpensive starting materials (*see "From the Labs," p. 91*). The work has been slow, however, in large part because engineers lack the tools to easily and predictably reprogram existing systems, let alone build new ones.

One problem is that the development of system components—genetic circuits, metabolic pathways, parts of enzymes—receives little emphasis in biology. Biologists who want to control gene expression, for example, usually use natural systems or slight variations on them. Although these redesigned biological control systems have generally served biologists' intended purposes (for example, production of a single pharmaceutical protein), they are often inadequate for more complicated engineering tasks.

Another problem is that there are few or no standards for biological components. In almost every other field of engineering, standardization makes it easy to combine parts made by different manufacturers. A similar system of standards that governs how biological components should work together would help biologists and biological engineers to design and build new devices.



Finally, of the biological components that are already available, many of the most effective have been patented. Open-source biological parts and devices, and eventually whole cells, could lead to engineered biological systems that are cheaper and better designed.

Standardized, readily available biological components, developed under an appropriate intellectual-property model, would open a promising new front in the biotechnology industry. Given the potential of synthetic biology, it is in our best interest to work out these details soon. TR

Jay Keasling is a professor of chemical engineering and bioengineering at the University of California, Berkeley.

Photo Essay

Brazil's Bounty

In Brazil during the 1990s—when oil prices were low, the national debt was high, and the state oil giant Petrobras was tapping into huge new oil reserves—the backers of biofuels struggled to keep their industry afloat. Then came September 11, the Iraq War, soaring oil demand from China, dissent within OPEC, and the oil shock that pushed prices over $70 a barrel. All of a sudden, biofuels—particularly ethanol—were the new oil. Brazil, as the world's largest exporter of ethanol, is a leader in developing this energy source.

By Stephan Herrera Photographs by Paulo Fridman/Polaris

Ethanol can be made biologically by fermenting sugars derived from food crops or from the cellulosic residue of switchgrass and wood. Brazil's ethanol is produced from the sugars of crushed and distilled sugarcane; production takes place mostly in the southeastern state of São Paulo, the country's most populous and industrial. Most of this sugarcane is milled and mashed, and the extracted juice is filtered, fermented, and distilled into ethanol by giant sugar-processing companies like Cosan *(right)* and Usina Cerradinho *(top and bottom left)*. Although the process is being mechanized, much of the sugarcane supplied to the Usina Cerradinho sugar mill and ethanol distillery is still harvested with little more than machetes, field rakes, and large trucks.


VEICULO LONGO

Photo Essay

There is nothing complicated about making ethanol from sugarcane. Like corn, on which both China and the United States rely heavily for ethanol production, sugarcane can be broken down into its simple sugars by heat and enzymes. The extracted juice can be easily processed, fermented, and distilled into ethanol *(top left and right)*. Little is wasted: leftover liquid and solid residues *(bottom left)* can be used for animal feed as well as for fuel for boilers and equipment on site. Thanks to a sustained government commitment to ethanol production—along with abundant land and sugarcane farms, favorable soil conditions, a long growing season, and relatively low wages—Brazil enjoys a competitive advantage in the ethanol business.

Photo Essay

At Cosan's Piracicaba plant, workers monitor the pH balance of the fermenting sugarcane juice to make sure it stays within its prescribed range *(top left)*. Not only is Cosan Brazil's largest ethanol producer, but it is easily the world's largest exporter of ethanol. In March, barely four months after Cosan floated an IPO on Brazil's Bovespa stock exchange, its stock price had tripled. Like Cosan, Usina Cerradinho *(bottom left and right)* is nearing the limits of its biofuel production capacity because of the growing global demand for ethanol. There is no guarantee, of course, that the price of oil will remain high, nor that other countries will turn as enthusiastically to ethanol as Brazil has. But even if neither happens, Brazil will have good reason to stay the course. Industry watchers say that because of economies of scale and rapidly improving fermentation technologies—such as novel enzymes *(see "Redesigning Life to Make Ethanol," p. 66)*—ethanol can remain competitive even if the price of oil drops to $40 per barrel.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Special Report

It's Not Too Late

Our planet faces a grave threat from global warming and climate change, which are caused largely by emissions of carbon dioxide and other greenhouse gases generated by human activity. Yet readily available energy technologies could be put in use today to forestall their worst effects. In this issue of *Technology Review*, we examine some of these technologies and argue that they require not further refinement but a considered, long-term strategy for their deployment.

Atmospheric levels of carbon dioxide—the most common greenhouse gas—have shot up 32 percent in the last 150 years. Geological evidence and climate science suggest that we are approaching a tipping point beyond which sea levels will rise catastrophically. Nevertheless, immediate steps to sharply reduce emissions could still prevent the worst consequences of global warming, according to famed NASA climatologist Jim Hansen (*see* **"The Messenger," by Mark Bowen, p. 38**). In the meantime, however, humankind is increasing, not decreasing, consumption of fossil fuels—and even getting cleverer about extracting them (*see* **"The Oil Frontier," by Bryant Urstadt, p. 44**). For the foreseeable future, we will continue to burn fossil fuels: they now provide 80 percent of the world's energy, and global energy demand will at least double by 2050. "Controlling carbon dioxide while also doubling energy use is a rather remarkable challenge to contemplate," mused Ernest J. Moniz, an MIT physicist and former undersecretary of the U.S. Department of Energy, earlier this year as he discussed an MIT research and education initiative aimed at confronting the energy crisis.

In meeting this remarkable challenge, we must, in particular, address the problem of coal. It is among the largest sources of carbon dioxide and, regrettably, is also the cheapest and most abundant fossil fuel. But cleaner technology—in which carbon dioxide could be captured and sequestered—is ready to go into new coal plants now (*see* **"The Dirty Secret," by David Talbot, p. 52**). Similarly, improved versions of today's nuclear power plants await construction (*see* **"The Best Nuclear Option," by Matthew L. Wald, p. 58**). Unfortunately, implementation of cleaner technologies has been thwarted by federal aimlessness. The Energy Department keeps changing its nuclear-research strategy, and a "FutureGen" zero-emission coal demonstration project announced three and a half years ago by President Bush hasn't yet picked a site.

At least one alternative energy technology is also coming into its own. Ethanol production from biomass is already a booming business in Brazil (*see* **"Brazil's Bounty," by Stephan Herrera, p. 28**); with help from bioengineered organisms, it could soon be efficient enough to compete directly with traditional energy sources (*see* **"Redesigning Life to Make Ethanol," by Jamie Shreeve, p. 66**).

There is no escaping the reality that in the end, we will need an energy economy based on solar, wind, and other renewables (*see* **"It's Not Too Early," by Marty Hoffert, p. 69**). We'd like to have an all-renewable energy portfolio today. But we cannot wait any longer for new technologies, as Joseph Romm, an Energy Department renewable-energy official during President Clinton's administration, made clear at a conference in April. "The point is," he said, "whatever technology we've got now—that's what we are stuck with to avoid catastrophic warming."

DAVID TALBOT

The best scientists, scrutinizing atmosphere, ice, earth, and sea . . .

...say global warming is approaching a tipping point beyond which catastrophic climate change and sea level rises will occur. Greenhouse-gas emissions from fossil fuels are a major culprit.

The Messenger

By Mark Bowen Portrait by Ben Baker

Jim Hansen may be the most respected climate scientist in the world. He's been director of NASA's premier climate research center, the Goddard Institute for Space Studies (GISS), for 25 years and a member of the National Academy of Sciences (NAS) for 10. And he more or less single-handedly turned global warming into an international issue one sweltering June day in 1988, when he told a group of reporters in a hearing room, just after testifying to a Senate committee, "It's time to stop waffling so much and say that the greenhouse effect is here and is affecting our climate now."

It took the rest of the scientific community about eight years to catch up with him on that point. He was ahead of the pack in 1988, and he remains so. He's been accurately predicting the progress of global warming for 25 years. And as the science grows ever more solid, owing in no small part to his own work, Hansen's predictions about an issue some see as the greatest threat civilization has ever faced are becoming ominously precise.

An attempt by the Bush administration to silence him early this year also helped turn global warming into one of the biggest news stories of 2006. It began on December 6, 2005, when Hansen declared in a talk at the American Geophysical Union in San Francisco that if our rate of fossil fuel burning continues to grow, we will eventually transform Earth into "a different planet." He presented an analysis showing that existing technologies can significantly cut greenhouse emissions, and suggested that a global solution requires leadership by the United States.

On December 15, he and three colleagues posted a routine monthly analysis on the GISS website, summarizing data from thousands of weather stations around the globe. It showed that 2005 was coming in as the warmest year since the mid-1800s. He was interviewed about this by ABC News.

According to NASA memorandums provided by Hansen, senior political appointees at NASA headquarters in Washington quickly called career public-affairs officers at the agency and directed them to give headquarters advance notice of Hansen's speaking schedule, his "data releases," and his attendance at scientific meetings. The career officers also understood from the phone calls that the posting of all content on the GISS website, including scientific data sets, would now require headquarters approval; that no NASA employees or contractors could grant media interviews without approval; and that public-affairs officers had the right to stand in for scientists in all interviews. Hansen emphasizes that the political appointees made sure to leave no paper trail. But by throwing off this muzzle, Hansen propelled himself—and global warming—into the headlines. The story broke on the front page of the *New York Times*; Hansen appeared on NPR and *60 Minutes*, too.

Through it all, he remained productive scientifically. One week, he submitted a paper to the *Proceedings of the National Academy of Sciences*; the next, he presented an invited talk at the NAS's annual meeting; the next, he filed a brief in U.S. District Court in California, as an expert witness for the state in a suit brought by automobile manufacturers hoping to strike down a 2004 regulation by the California Air Resources Board that would eventually reduce greenhouse-gas emissions from vehicles sold in the state by about a third.

Hansen now starts off most public appearances by stating that he speaks as a private citizen, not a public employee, that his opinions are those of a climate scientist with more than 30 years' experience, not of a government policymaker. Indeed, he asked to be interviewed not at his institute, on the campus of Columbia University, but at the small apartment he keeps nearby.

Over lunch in a tasteful but spartan living room on the top floor of a building that affords magnificent southwest views of the Hudson River and the western half of Manhattan, he sits in jeans and an untucked blue-checked shirt, without shoes, sipping his fourth or fifth coffee of the day.

He says he's been muzzled before—during the Reagan and first Bush administrations—but that in more than three decades as a government employee, he has seen nothing to equal the recent clampdown. He is angry, but he expresses his anger calmly.

The Science

Hansen is a planetary scientist. He earned his doctorate from the University of Iowa's department of physics and astronomy, when it was chaired by the legendary astrophysicist James Van Allen. For his dissertation, Hansen investigated the effect of atmospheric dust on the temperature of Venus; and it may be that this early work imparted a special knack for viewing Earth's climate system as a whole. He joined GISS as a staff scientist in 1972 and was promoted to director in 1981. For more than 30 years, he and his dedicated research team have been producing work at the forefront of climate science.

He often employs a favorite quote from the late physicist Richard Feynman to explain his approach: "The only way to have real success in science ... is to describe the evidence very carefully without regard to the way you feel it should be. If you have a theory, you must try to explain what's good about it and what's bad about it equally. In science you learn a kind of standard integrity and honesty." Hansen invariably points out the shortcomings in his own arguments. When another scientist presents only the points that support his conclusion, Hansen will chide him for acting "like a lawyer."

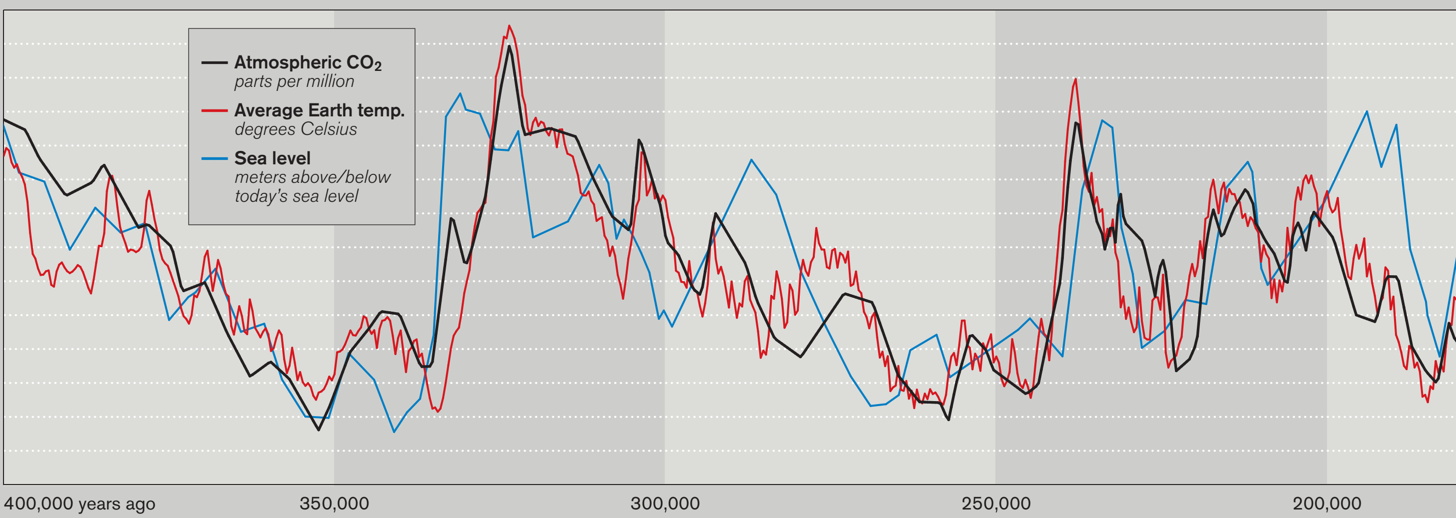
For about 25 years, however, the data have been telling him that Earth is getting warmer, humans are causing it, and this is bad news. In his view, moreover, the science has become so airtight in the last five years that the immense danger posed by greenhouse emissions can no longer be denied. This has placed him on a collision course with politicians and business leaders who want a different answer.

Hansen's December talk was given in honor of greenhouse pioneer Charles David Keeling. Keeling monitored carbon

CO_2 and the "Ornery Climate Beast"

How might today's human-caused increases in atmospheric concentrations of carbon dioxide and other greenhouse gases change the planet? The past provides clues. Geological records show that in the past 400,000 years, atmospheric concentrations of carbon dioxide, average Earth temperature, and sea levels have risen and fallen roughly in tandem, in 100,000-year cycles paced by slight oscillations in Earth's orbit. These oscillations affect the distribution of sunlight, hardly affecting the total amount reaching Earth; yet, scientists believe, this has been enough to set in motion chains of events that raise and lower temperatures, launch and end ice ages, and trigger vast changes in sea level.

What's coming next? Carbon dioxide—the number one greenhouse gas—has



Source: NASA Goddard Institute for Space Studies

dioxide on the summit of Hawaii's Mauna Loa for almost 50 years, from 1958 until his death about six months before the meeting, and demonstrated that the concentration of atmospheric carbon dioxide had been rising the whole time.

Early in the talk, Hansen presented what may be the scariest graph in climate science, a 420,000-year record of carbon dioxide and temperature, inferred from a 3.6-kilometer ice core recovered at Russia's Vostok station in Antarctica *(see "CO_2 and the 'Ornery Climate Beast,'" below)*. This graph puts the whole greenhouse story in a nutshell and demonstrates, as Columbia climatologist Wallace Broecker once put it, that "Earth's climate system is an ornery beast which overreacts even to small nudges."

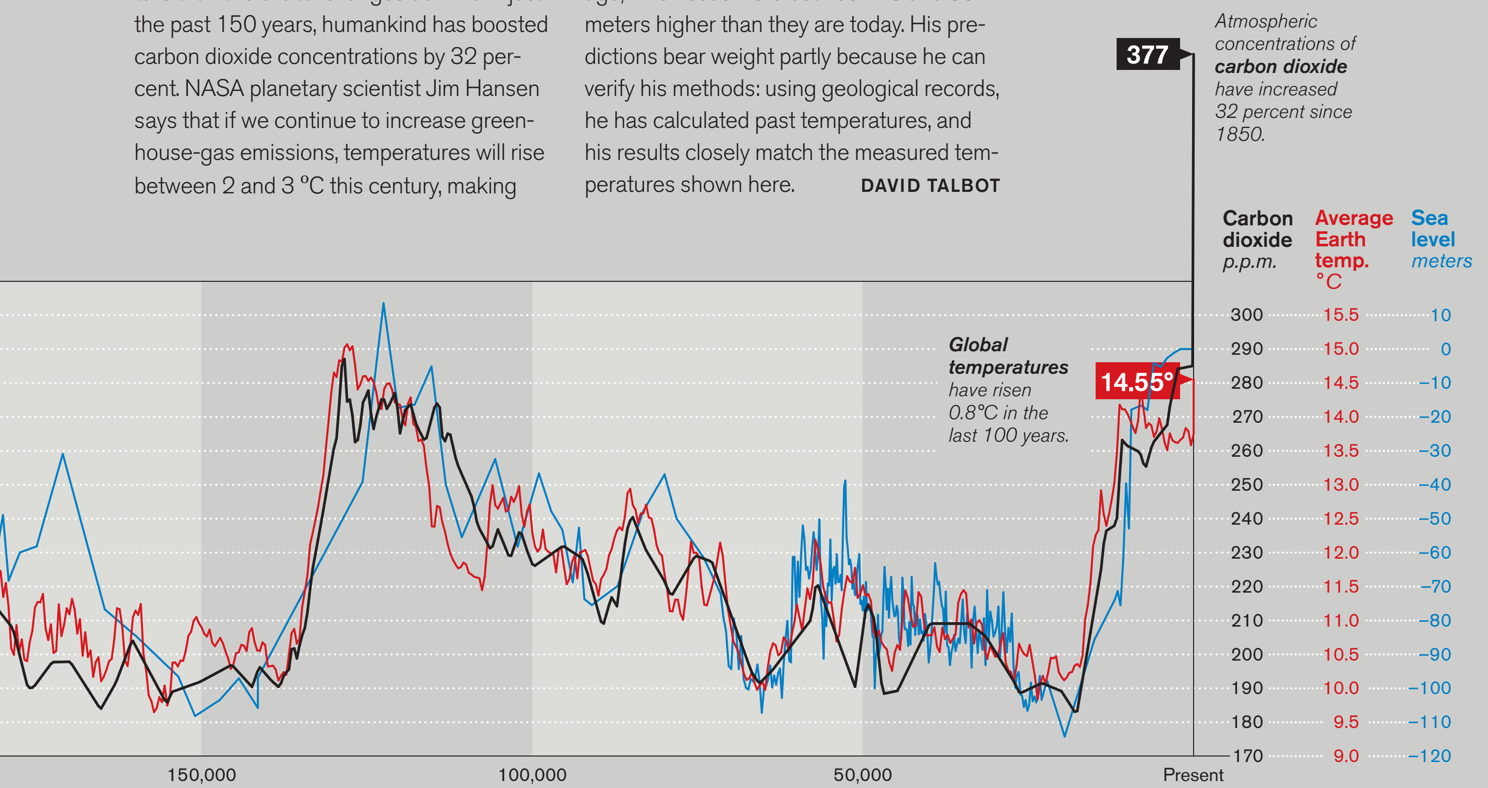
Past atmospheric temperatures at Vostok may be inferred by measuring the ratio of deuterium to hydrogen, layer by layer, in the water molecules of the ice. Ancient carbon dioxide levels are recorded in the air bubbles trapped in the ice These records show that temperature and carbon dioxide tracked each other for all but the last 200 years—both oscillating in a cycle that repeats about every 100,000 years, in step with minute changes in the shape of Earth's orbit around the Sun. Dips in carbon dioxide and temperature correspond to ice ages, or "glacials," and peaks to interglacials—such as the present warm period, which began about 12,000 years ago.

In the early 1800s, shortly after the start of the industrial era, carbon dioxide began to skyrocket, while temperature remained flat. Temperature began to spike only about 30 years ago. In contrast, temperature changes preceded carbon dioxide changes at Vostok until the beginning of the industrial era. Scientists believe these natural changes in carbon dioxide were a feedback response to initial, small changes in temperature, and that those changes—along with other responses—amplified the original temperature shifts.

The other responses included changes in the levels of other greenhouse gases, primarily methane; changes in the area covered by polar ice sheets and sea ice, which reflect sunlight back into space and cool the planet; changes in the levels of dust and airborne aerosols, which also cool by reflecting sunlight (the "parasol effect"); and changes in the mix of grassland, desert, and forest, which affect the reflectivity of the land.

The history of these factors is known. Besides the information about greenhouse-gas levels from the trapped air bubbles at Vostok, a sediment core from the bottom of the Red Sea indicates changes in sea level, which in turn give an approximation of ice sheet area. (The ice sheets grew and thereby drained the oceans during cold times; they melted to refill them during warm times.)

much more power to affect Earth's temperature than the orbital changes do. And in just the past 150 years, humankind has boosted carbon dioxide concentrations by 32 percent. NASA planetary scientist Jim Hansen says that if we continue to increase greenhouse-gas emissions, temperatures will rise between 2 and 3 °C this century, making Earth as warm as it was three million years ago, when seas were between 15 and 35 meters higher than they are today. His predictions bear weight partly because he can verify his methods: using geological records, he has calculated past temperatures, and his results closely match the measured temperatures shown here. **DAVID TALBOT**



Using these and other geological records, Hansen can calculate Earth's temperature at any given time in the past 420,000 years. He plugs in the data for greenhouse levels, sea level, and so on to produce a temperature estimate for the corresponding time. And as he showed his audience last December, these calculations match temperatures as recorded by the deuterium and hydrogen in Vostok's ice quite precisely over the entire 420,000-year span.

Global-warming deniers like to complain that scientists base their predictions on faulty computer models. But Hansen's calculations show that we don't need a computer to know how temperature will respond to a given change in the greenhouse—or a change in dustiness, or forest cover, or the amount of ice on the Arctic Ocean. Solid geological field data give us everything we need—and provide a check for computer models. And lend credibility to Hansen's predictions.

Besides demonstrating his firm grasp of the power of these various factors to change temperatures, this remarkable matching of theory to real-world data also tells us just how ornery the climate beast may be: the orbital changes that paced the ice ages were incredibly small. They had little effect on the total amount of sunlight reaching Earth in a single year—only its distribution over seasons and latitudes. Nevertheless, these minute redistributions led to swings in temperature of about 5 °C and variations in sea level of more than 100 meters.

Greenhouse-gas levels, on the other hand, are more like a knob controlling the brightness of the sun. And the turning up of the rheostat that humanity has accomplished by adding about a trillion tons of carbon dioxide to the atmosphere thus far in the industrial era dwarfs the redistributions in sunlight that once switched the planet back and forth between glacials and interglacials. We are poking the climate beast in a way it has not been poked in the entire era of cyclical ice ages—at least two million years. As Hansen told his audience last December, "Humans now control global climate, for better or worse."

A Slippery Slope

More than 20 years ago, Hansen also explained why global warming has lagged the greenhouse buildup. In 1985, he suggested that it should take between 50 and 100 years for the excess energy reaching the planetary surface to have its full effect on temperature, because the energy will first go to heating the oceans; only when they begin to warm will the atmosphere follow suit. Just last year, when studies demonstrating a global rise in ocean temperatures confirmed his thinking, Hansen began referring to the heating of the oceans as the "smoking gun" of global warming.

Another factor, which Hansen and GISS modeling specialist Andy Lacis have termed a "Faustian bargain," also suppresses atmospheric warming. In 1990, Hansen and Lacis showed that traditional air pollution has produced a mighty parasol effect. We send dust and aerosols into the air from tailpipes and smokestacks, by burning the wood and dung that provide heat and light to hundreds of millions of the world's very poor, and through slash-and-burn agriculture and other land use practices that have exposed vast tracts of dried-out, eroded soil to the blowing wind. The dimming of incident sunlight caused by reflection from these airborne particles now offsets about half the warming of the industrial age.

To continue offsetting our growing greenhouse emissions, we would have to maintain the rapid growth of traditional, noxious air pollution. But the United States and Europe have begun controlling it, and the dismal air quality in Beijing and Mumbai is convincing the Chinese and Indians that they must, too. Faust's payment to the greenhouse is now coming due.

Owing to greenhouse changes we have already incurred, Hansen told his audience in San Francisco, Earth's temperature will rise about 0.5 °C in the next 50 years even if we stop burning fossil fuels today. We're on a slippery slope: we could cross a threshold that leads to a drastically different planet, half a century before knowing that we've done so. Hansen believes we are horrifyingly close to such a threshold, and that we will cross it if we don't change our greenhouse ways within the next few years.

Earth is now passing upward through the highest temperatures of the past 12,000 years, and the half a degree that is already in the pipeline will bring temperatures within half a degree of the high points they have reached only a few times in the past two million years. During a warm period about 120,000 years ago, for example, sea levels were probably five or six meters higher than they are today.

Running future emissions scenarios on a GISS computer model, Hansen finds that if we remain on the path he calls "business as usual," temperatures will rise between two and three degrees this century, making Earth as warm as it was about three million years ago, when the seas were between 15 and 35 meters higher than they are today. There go many major cities and the dwellings of about half a billion people.

Evidence suggests that the seas could rise in a matter of decades or centuries; recent events in Greenland and Antarctica indicate that the process may already have begun. The last great ice sheet collapse, about 14,000 years ago, sent the seas up a total of 20 meters, at the rate of one meter every 20 years for 400 years. Just the first meter would obliterate New Orleans, force tens of millions of people in Bangladesh to emigrate, and inundate rice-growing river deltas throughout Asia, a major food source for our species.

A Solution

Yet Hansen continues to believe we can forestall disaster. In June 2000 his group charted a course for holding future temperatures below the danger level. They named this departure from business as usual the Alternative or A-Scenario.

His characteristic "whole systems" approach revealed some wiggle room on the hardest conundrum, carbon dioxide—which, as a direct by-product of fossil-fuel burning, is intrinsic to the global energy infrastructure. Though he warned that carbon dioxide emissions must be stabilized over the next few decades, he also suggested that significant progress could be made by reducing the emissions of other greenhouse gases, particularly methane and ozone—and that we must pay our Faustian debt involving air pollution.

Eliminating black carbon soot, which comes mainly from household heating systems, vehicles, and fires, would be a good place to start. Besides promoting asthma and other respiratory problems, soot heats rather than cools the air: it absorbs rather than reflects sunlight, owing to its color. Some soot emissions continue to heat the planet even after leaving the air, by settling on polar ice sheets and mountain glaciers, darkening their surfaces, and helping them melt. Carbon monoxide and ozone are powerful greenhouse gases as well as dangerous pollutants, ozone having an estimated impact on human health and crop productivity of $10 billion per year in the United States alone.

Still, the main greenhouse promoter in coming decades will be carbon dioxide. In 2001, Hansen assembled the "A-Team," made up of GISS researchers and students and teachers from schools in the New York City area, to tackle the problem of providing for the world's growing energy needs while adhering to the A-Scenario. They found that efficiencies based on existing technologies could buy time for a few decades, after which we must employ new technologies to cut global carbon dioxide emissions by 60 to 80 percent.

The A-Team found that growing emissions from coal-burning power plants and transportation posed the greatest threats. "Efficiency of energy end-use in the near term is critical for the sake of avoiding new, long-lived CO_2-producing infrastructure," Hansen notes. "Green" building codes, combined with energy-efficient lighting and appliances, would be sufficient to hold electrical needs—and the number of power plants—constant for many years. The team also developed an achievable plan for limiting vehicular emissions, a plan that starts by improving fuel efficiency with existing technologies. It is "technically possible to avoid the grim 'business-as-usual' climate change," said Hansen last December. "If an alternative scenario is practical, has multiple benefits, and makes good common sense, why are we not doing it?"

He knew the answer from personal experience. Few remember that Vice President Dick Cheney chaired a cabinet-level climate-change working group in 2001, shortly after convening his infamous energy task force. Hansen briefed the group twice. He believed in those early days that the White House was open to a discussion of facts and potential solutions. But as he remembers it, Cheney picked only the cherry he liked from the Alternative Scenario: its emphasis on soot and the lesser greenhouse gases. He used this to justify ignoring carbon dioxide.

Indeed, the energy policy Cheney introduced poses a tremendous climatic danger. It relies on increasing supplies through oil drilling in the Arctic National Wildlife Refuge; opening other public lands to coal, natural-gas, and oil exploitation; and constructing more than 1,000 new power plants. So Hansen convened the A-Team. He had a second interaction with the White House in 2003, again with little effect. By the time of his talk in honor of Charles David Keeling, he had run out of patience. "It seems to me," he said, "that special interests have been a roadblock wielding undue influence over policymakers."

In his living room overlooking the Hudson, Hansen tells me that climatologists have now "made the science story much stronger than it was in 2000." Yet, he says, "we have not been able to impact the U.S. position. And when you get to the further step, where not only do you have the information to make the story clear but you have this censorship, you know, that's when you really get angry. I think the only way to get action now is for the public to get angry, [for] the public [to] see the frustration and … see that we have political leaders who are under the thumb of special interests. …

"No court of justice or court of international opinion will forgive us for what we're doing now, because now we know the problem and we're just pretending we don't understand it. We are going to be responsible, but it will be our children and grandchildren that have to pay." TR

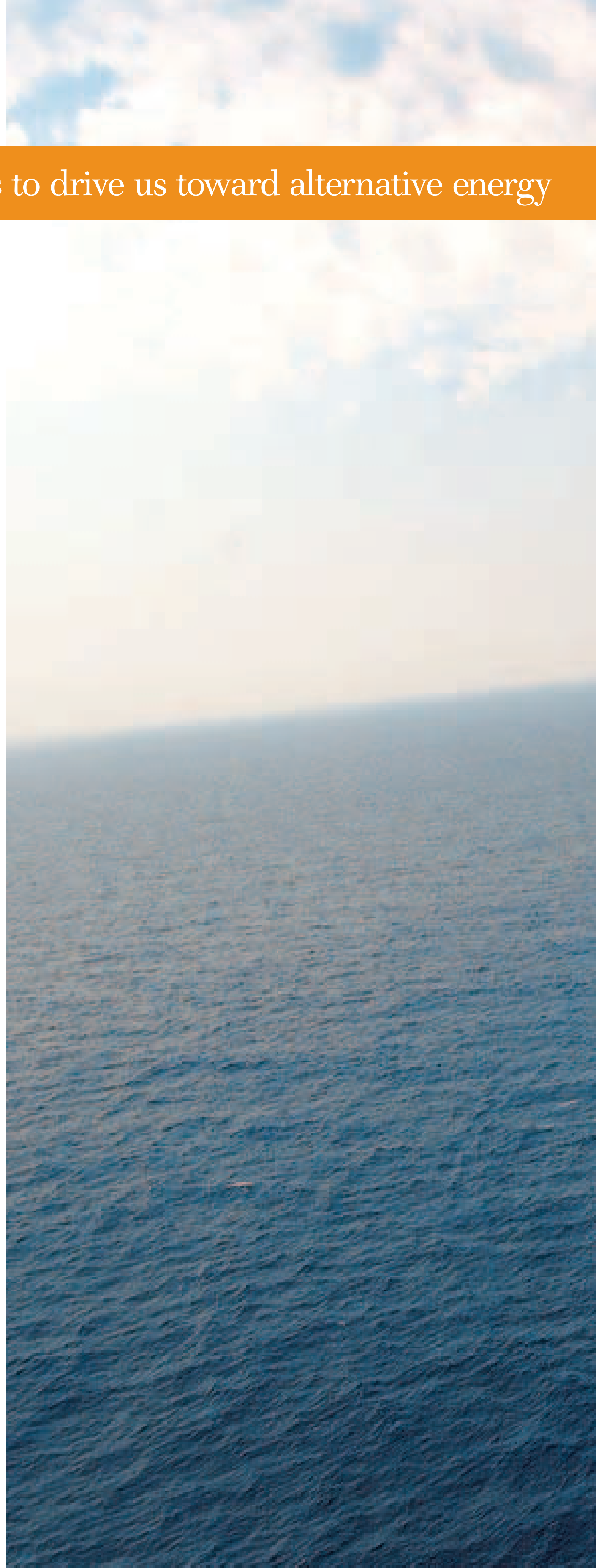
Mark Bowen is the author of Thin Ice: Unlocking the Secrets of Climate in the World's Highest Mountains.

Global temperature will continue to rise, but we still have time to keep it from reaching catastrophic levels. Even as we consider ways to reduce carbon dioxide and other greenhouse gases, however, …

…don't expect the scarcity of fossil fuels to drive us toward alternative energy

The Oil Frontier

By Bryant Urstadt Photographs by Paul Taggart



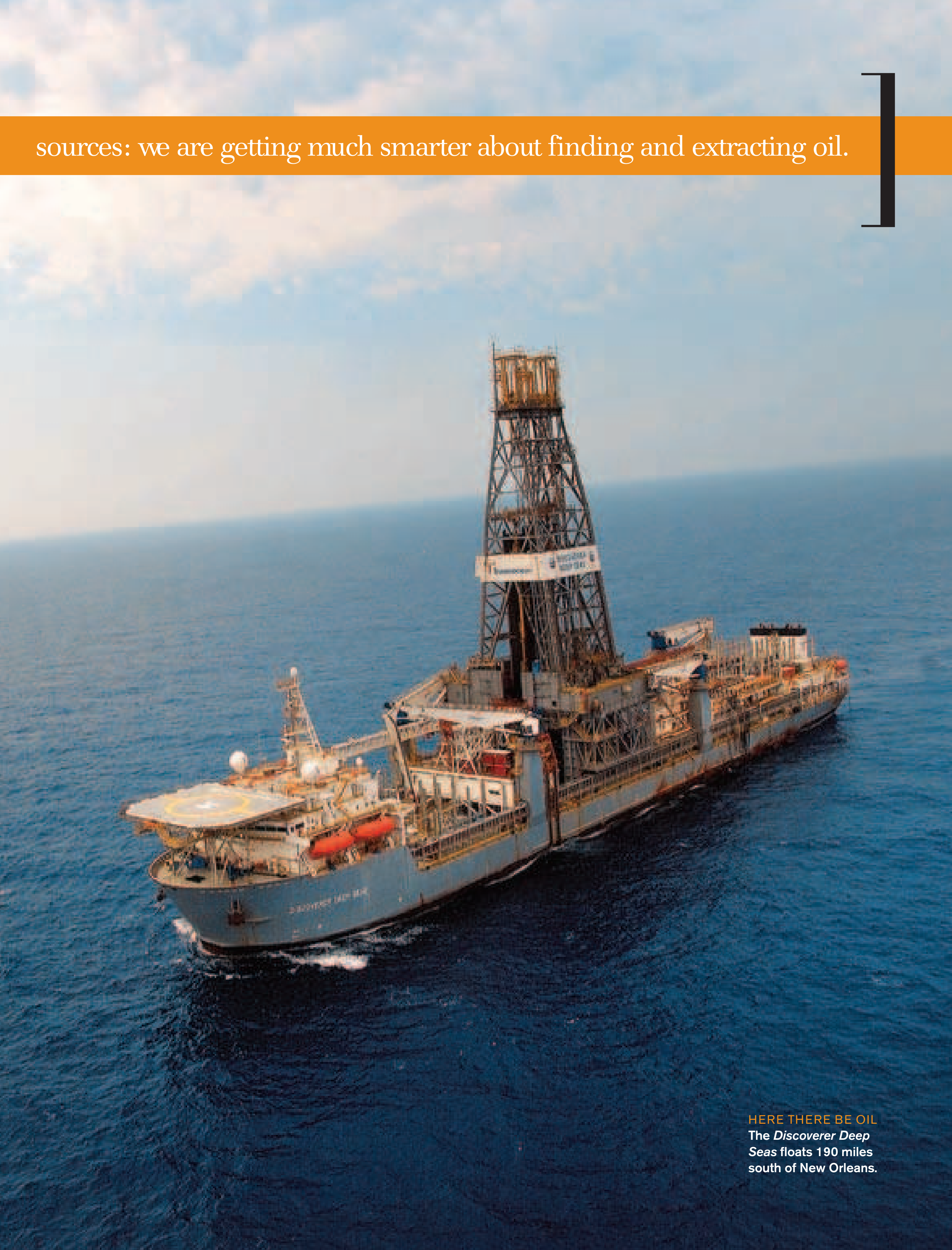
The easy oil is gone. To get to the new oil, you board a yellow Bell 407 helicopter outside New Orleans and fly south, touching down 140 miles offshore, on a ship that's drilling holes in the seabed nearly a mile below.

Along the way, you fly down a 50-year timeline of American offshore oil extraction. Through the glass panel at your feet, you watch the delta slide by with its flat islands of green and its fishing camps, occasionally passing the remains of a barge rig—the first and simplest waterborne oil rigs, which simply settled in the mud and drilled. After the barrier islands come the brown waters of the continental shelf of the Gulf of Mexico. Here, the platforms increase in number but are only slightly more complicated; of the roughly 4,000 platforms in the gulf, most are simple scaffolds standing on the bottom in 30 to 200 feet of water.

But the barge rigs and the fixed-leg platforms are the past. So you keep flying, and the rigs grow scarcer but larger, until you leave the silty waters and hit the blue of the deep water, which shimmers like an opal lit from within.

Out here, 4,300 feet above the seafloor, floats *Discoverer Deep Seas*. Leased by Chevron, it's a ship that would have been too expensive to use 10 years ago, a ship that represents 20 years of advances in the art and science of oil extraction. It's not particularly beautiful. With its derrick amidships and its rusty waterline, *Deep Seas* looks like a ghost tanker trying to make off with the Eiffel Tower. But it is a breathtaking expression of ingenuity, and a glimpse of what we'll increasingly have to do to get energy.

sources: we are getting much smarter about finding and extracting oil.



HERE THERE BE OIL
The *Discoverer Deep Seas* floats 190 miles south of New Orleans.

BUSINESS END Drill bits on *Deep Seas* run about $80,000 each. Beneath the ship's derrick is the "moon pool" (opposite), where the drill string is submerged, piece by piece.

The ship is so big that my incomplete tour will take a day. It's 835 feet long—on end, it would be the height of an 80-story skyscraper—and 125 feet wide. Because it is so tightly packed with machinery, a visitor winds through *Deep Seas* rather than walking its perimeter, as one might on a cruise ship, and never gains a full sense of its size.

My guide is Eddie Coleman, the lead drill-site manager on *Deep Seas*. A quiet Texan in a denim Chevron shirt and jeans, Coleman has spent the past 32 years offshore, working two weeks on and two weeks off, shuttling between his home of Brookhaven, MS, and platforms and drillships progressively farther offshore and more advanced. Like most of the people I meet in this business, he says he wouldn't want to do anything else.

Coleman is in a decent mood, but he could be happier. Last night, the drilling in a well that Chevron calls PS002 stalled at 20,351 feet. *Deep Seas* doesn't produce oil; it drills for it, capping the wells and leaving them to be put into "production" by equally expensive and complicated floating platforms. The oil field that *Deep Seas* is exploring is called Tahiti, and it's about 24,000 feet below a 5-by-1.5-mile section of seafloor leased from the Minerals Management Service of the U.S. government, in an area known as Green Canyon. PS002 is the second well of a scheduled six, and the whole field is slated to go into production in 2008. Chevron hopes to pump 125,000 barrels a day out of Tahiti.

Pumping is a long way off, though, and now the drilling has stopped, too. "We tagged something," explains Coleman, "but we're not sure what. So we're tripping right now." To "trip" means to bring the drill bit back up or send it back down. Coleman and a team back in Houston have decided that the casing, the tube that is dropped down in increasingly narrow segments as drilling progresses, in order to maintain the integrity of the well, has probably gotten out of round or developed a spur of some kind. So once they've tripped the bit back up, they'll send down a mill to bore out the casing. And when they've retracted the mill, the bit will have to be tripped down again.

The trip takes about 12 to 13 hours either way, and it's expensive. *Deep Seas* is leased from a company called Transocean, and the daily rent is about $250,000. With the cost of labor and equipment, drilling in Green Canyon costs Chevron around $500,000 a day. Casing, for instance, costs around $100 per foot. The drill bits run around $80,000 each, and there are 140 to 175 well-paid people onboard, from cooks to highly trained geologists. Developing the Tahiti field will cost about $3.5 billion.

Because of the resulting financial pressure, *Deep Seas* hasn't been back to shore since it was launched five years ago. Every six months or so, a supply ship pulls up alongside and pumps a million gallons of diesel onboard. The fill-up takes about 24 hours. The diesel runs six generators,

which send five megawatts of power to each of six electric omnidirectional thrusters, which keep the ship in position. On a calm day like this, the thrusters, fed by GPS data and overseen by a team of dynamic-positioning operators on the bridge, keep the 100,000-metric-ton ship essentially stationary; it drifts only by inches over the well below.

A Race to the Bottom

The term "deepwater" generally refers to wells drilled in more than 1,000 feet of water, and Chevron, like all the big oil companies, has kept a weather eye on deepwater prospects for years. An exploration well in the leased Green Canyon region, for instance, was drilled in March 2002, and it went down 28,411 feet, through a two-mile-thick layer of salt and into a 400-foot-deep pay zone of sand and oil.

In November 2002, Chevron began developing the oil field, starting with a series of appraisal wells drilled at its estimated north and south ends to offer a clearer idea of what was there. The results were better than Chevron expected. The pay zone looked to be 1,000 feet thick and 7.5 square miles in size. If all goes well, Tahiti ought to be about a 500-million-barrel field, a huge find in today's market.

Lured by such prospects, oil companies have been pressing into ever deeper water, with Chevron, Kerr-McGee, and BP leading the field in the Gulf of Mexico. Abroad, major prospects include the waters off West Africa, the South

China Sea, and possibly even the Mediterranean. From 1997 to 2003, the number of deepwater projects in the Gulf of Mexico grew from 17 to 86. The number of ultradeepwater projects in the gulf, those in more than 5,000 feet of water, has more than doubled in the last two years alone. In the past 10 years, as inshore wells have slowed down, deepwater oil production has risen more than 840 percent.

When Chevron began developing Tahiti, it ordered a platform. Like everything in the deepwater field, platforms are moving toward new heights of size, complexity, and cost. They can't simply rest on columns driven into the seabed, so they have to float; but otherwise, their design varies. Some platforms, like BP's *Thunder Horse*—currently the largest, it is bigger than the largest aircraft carriers and took 15 million man-hours to build—float on pontoons. Tahiti's platform will be designed as a spar, which is often likened to a Coke can. The spar is delivered horizontally to the site and then tipped into place as its bottom fills with saltwater ballast.

At a time when oil prices have been as high as $75 a barrel, such costly equipment more than pays. It follows that Chevron and Transocean have already worked out a long-term lease on a yet larger ship, *Discoverer Clear Leader*, which is to be delivered in 2009 and will cost Transocean some $650 million to build. Similar in many ways to *Deep Seas*, it will have a larger drive unit at the top of the derrick, allowing it to drill in up to 12,000 feet of water, boring as far as 40,000 feet below sea level. It's expected to cost Chevron roughly $750,000 a day to lease and operate.

Twelve thousand feet of water is bordering on the practical limit of exploration, at least in the Gulf of Mexico. It may not be as far as technology can take deepwater drilling, but it is probably as deep as Chevron will need to go to get oil. "Get any deeper, and you're leaving the sedimentary deposits of organic matter that make oil," says Paul Siegele, who oversees the company's offshore exploration and development in the gulf. "The bottom of the deep ocean is just solid basalt." Not that the oil companies haven't started to survey the deepest ocean floors anyway, just in case.

Roughnecks and Mud

Coleman takes us through the *Deep Seas*' 200-bunk living quarters, its offices, and the bridge, and then out onto a catwalk that hovers over the deck. Below is a rack holding "risers," 75-foot-long sections of pipe that house the drill string on its way to the seafloor. The drill string isn't actually a wobbly piece of cable but a series of 130-foot-long hollow pipes "strung" together, which push the bit down through the risers and into the earth. Enormous cranes lift each section of riser onto a conveyor belt. The belt then tips and guides each riser into position in the derrick.

The catwalk follows the riser belt onto the drill floor of the 226-foot-tall derrick. It's the derrick, a giant scaffold narrowing toward a peak, that you think of when you think of an oil well. From it hangs the hook holding the drive that spins the drill string and the bit below. There used to be a guy way up there, on what's called the monkey board, but automatic pipe-racking systems have recently replaced him. Dozens of sections of drill string are stacked inside the *Deep Seas*' derrick, and they swing with the slow motion of the ship. Beneath the drill floor—which we'll visit later—is the moon pool, the one spot of transcendent beauty on *Deep Seas*. There, the risers and the drill string within vanish into a pellucid square of water, fish shimmering around them.

Right now, two roughnecks—and yes, they still call themselves roughnecks—are helping guide sections of drill string down an opening in the drill floor, directing a machine that connects the segments. Overseeing the roughnecks are about eight guys watching computers in the glassed-in driller shack. They monitor information from sensors embedded in the drill, which measure things like how much weight the hook at the top of the derrick is holding, the pressure inside and outside the drill string, and the speed at which the bit is turning.

We leave the derrick and head down a few stories to see the mud module, which looks a little like a cross between a brewery and a sewage treatment plant. "Mud" is one of the most important tools in the driller's kit, though it is rarely thought about or mentioned outside the industry. A synthetic or petroleum-based lubricant, mud is sometimes said to look like chocolate milk. Deepwater drilling requires the synthetic version, which was developed in the mid-1990s. It has two outstanding qualities: it maintains its lubricating properties under higher pressures than the traditional diesel-based mud, and it's not classified as a pollutant by the U.S. Environmental Protection Agency. In the mud module, just past the derrick, are stored 15,000 barrels of the stuff, which—at $165 a barrel—is a king's ransom in mud.

Mud does more than lubricate, though. It is pumped down the well—through the drill string and out the bit—and it comes back up inside the riser, bringing with it "cuttings," chips and shards of sediment and rock. Mud can be made in different weights, and at great depth it exerts immense pressure on the casing and on the walls of the "hole"—the freshly drilled bottom of the well. That keeps equally huge geological pressures from collapsing the well or, worse, starting oil flow too early, which is the definition of a "blowout." Spindletop, the 1901 Texas well that rained something like 800,000 barrels of crude on amazed prospectors, is the classic example of a blowout.

After leaving the mud module, we head back along the deck until we meet *Hercules*, a remote-controlled submarine, which is currently sitting under a crane and ready to swing out alongside the ship. At 4,000 feet below, everything is done by the unmanned *Hercules*; it is simply too

WEATHER EYE **On the bridge, operators monitor (clockwise from upper left) drilling data, the moon pool, the chopper deck, and two depictions of the ship's position over the well.**

deep for human divers. *Hercules* is a box of mechanical arms, propellers, cameras, and lights overseen by contract technicians. Of its two remote arms, one is controlled by joystick and the other by a glove of sensors attached to the hand and arm of the operator. The setup is accurate enough to turn a half-dollar-sized bolt with a wrench.

The $8 Million Question

In some ways, *Deep Seas* itself is a remote vehicle, directed by Chevron's Houston office. This becomes clear on our return to Houston, where, the next morning, we watch Curt Newhouse at work. It's just before 8:00, and Newhouse is sitting in a room with 20 other people, trying to make a decision. If his decision is wrong, it will be expensive; in his job, pretty much every type of error is. "No matter what, it always seems to take about $8 million to fix," he says.

A Louisiana native, Newhouse has been working at Chevron for 24 years and is now senior drilling superintendent for *Discoverer Deep Seas*. Even though he's running things, he's only onboard about four to six times a year.

The room he's sitting in is called the WellDecc, or Well Design and Execution Collaboration Center. Here, every morning, Newhouse and a group of geologists, petroleum engineers, and earth scientists—the subsurface team—gather to decide what to do next on *Deep Seas*.

In the WellDecc is a conference table that does not quite accommodate all the staffers. Crammed in, they all face a wide screen, which has a number of windows projected on it, controlled by a desktop computer and a wireless keyboard in front of Newhouse. One window is a video feed of the team on the *Deep Seas*, while another shows the group in the WellDecc. Another window is a graphic display of the progress of the bit, and the last is dense with numerical measurements from the well. Newhouse will move and manipulate these and add others throughout the conference.

Newhouse's staff has been watching everything that has happened on the drillship in the past 24 hours. Information about mud weight, bit depth and speed, the resistance of the material being bored through (to determine whether it contains oil or water), and the kind of stuff coming up with the mud is all uploaded to Houston, where it is pored over in each cubicle until the group gathers each morning.

Because of what he has learned about yesterday's drilling, geologist David Rodrick is worried that the bit is moving too quickly through the layers of the Miocene era, which settled between 5 million and 23 million years ago.

There are many such layers—containing a lot of sand—and Chevron numbers them by their rough age in millions of years. In this well, the bit is at M12, the pay zone is at M21, and each level is at a different pressure. Drilling from one layer down to another is a delicate operation, and the integrity of the hole is maintained by the pressure of the mud pumped into it. Too little pressure and the hole or the casing above it could collapse. Too much and leaks could develop, or fractures in the rock, disturbing mud circulation.

Having already drilled two wells nearby, the subsurface team knows that at M17, the pressure ramps up quickly. The $8 million question is when to stop drilling and step down to the next size in casing which can withstand more intense pressure. Reduce the casing size too early and you needlessly

SEA ROVER *Deep Seas*' remote submarine, *Hercules*, does the work 4,000 feet below.

lose valuable oil flow. "We don't want a straw down there," says Newhouse. "We want to see a good 30,000 bar rels a day." Stick with the bigger casing too long, and the deepest part of the well may collapse before it can be cased.

Newhouse, though, isn't convinced the bit is close enough to the M17 sands to change the casing yet. He's thinking about the future of the well, 10 years down the road, and he wants to see a good flow, not an overly conservative casing decision.

The group decides to continue drilling, but slowly, and to watch the numbers on their desktops as they come in. Rodrick is tentative about the decision. As the meeting is winding down, he reiterates, "You don't want to get within 200 feet of those M17 sands, because those pressures will come up fast. If we don't watch out, it's going to eat our lunch."

Looking for More

Behind the drillships and platforms, and the superintendent in the WellDecc, are the computer geeks, whose efforts to guess where the oil is are often credited with enabling the deepwater rush. One of them is Barney Issen, the Jerry Garcia of Big Oil. A guy with a beard and long wavy black hair parted in the middle, he happily admits to driving for years with a "Question Authority" bumper sticker on his car. He has questioned how the earth came to be, too. "Most of us ended up here because we had that moment on the mountain, wondering how it all came to pass, and how we could learn more about it," he says. For Issen, that path led to a degree in geophysics—he originally wanted to work on a moon shot—and a job running the computers at Chevron.

To get an idea of where oil is, ships with special air cannons send out blasts of vibration, which travel down tens of thousands of feet and back. The velocity of the returning signals, and their round-trip times, are recorded by sensors on miles-long cables dragged behind the ship. Signals reflected by different strata have different speeds, which helps geologists picture what lies below the ocean floor. The big problem in deep water is the layers of subsurface salt, which refract vibrations in confusing ways. "It's like trying to see things through those cubes of glass, or through the edge of a fish tank," explains Issen.

Every year, Issen gets better at making sense of erratic signals. Computers have been getting faster and algorithms more powerful, and oil companies are beginning to be able to see through the salt with some degree of certainty.

When Chevron gets ready to talk about drilling, it gathers with investors, often other oil companies. They meet in a room they call the Visualization Center, and they all look at Issen's models on an 8-by-25-foot screen. Sometimes the decision makers don 3-D glasses. Other companies have even experimented with projecting models of the seabed on 360-degree surround screens in an environment called a "cave," but, says Issen, "that can be more cool than useful." Investors bring their own models to the conversation, and a consensus about where the oil is begins to emerge. It's still a business that requires guesswork: three out of four deepwater drills are unsuccessful. But not long ago, companies drilling on land hit oil in only one of every ten wells.

As the oil companies get better at finding the oil, though, the oil is getting harder to find. Optimists believe that the march of technology, embodied by *Deep Seas*, will enable companies to extract more and more oil from previously "depleted" fields while continuing to get better at finding and developing new fields. My visit to *Deep Seas*, and the time I spent with Chevron's geologists, seemed to give credence to the optimists' view of things. A shortage of oil, it appeared, was only a shortage of ships, computers, and other drilling technology.

But while it is true that a lot of good oil is left in the deep waters of the Gulf of Mexico—the Minerals Management Service estimates that about 44.5 billion barrels of oil remain to be discovered—deepwater drilling is only a small part of the solution to the oil shortage. Although Chevron considers the 500-million-barrel Tahiti field an "elephant" of a find, for example, elephants aren't what they used to be. Saudi Arabia's Ghawar field, which was tapped in 1951, has already yielded some 54 billion barrels and may have 70 billion more. The United States alone, meanwhile, consumes roughly 20 million barrels of oil every day.

Money will help, though. The higher prices go, the more oil companies can do. While discussing other projects, Siegele mentioned that the economic "breakover" point for mining the tar sands of Alberta was north of $60 a barrel; oil had reached $75 that day. There may be 150 to 300 billion barrels of recoverable oil in those sands. As for Issen, he is looking forward to mapping new territory and using better seismic imaging. "There's a lot of uncertainty, yes," he says. "But clearly, we think there's real potential." TR

Bryant Urstadt has written for Harper's *and* Rolling Stone.

We need a realistic strategy. Since humankind will inevitably be drilling for and digging up more and more fossil fuels, we must begin to …

… use cleaner fossil-fuel technologies and to sequester carbon dioxide. In the case of coal, a major source of carbon dioxide emission, better technologies exist; the question is how to get people to adopt them.

The Dirty Secret

By David Talbot

Coal is the black sheep of the energy family. Uniquely abundant among the fossil fuels, it is also among the worst emitters of greenhouse gases. Mindful of coal's bad reputation, President Bush promised the world three and half years ago that the United States would develop a superclean coal plant in an initiative known as FutureGen. The plant would have zero emissions; even the carbon dioxide it released would be pumped underground.

Today there is a patch of land in Great Bend, OH, where an advanced coal plant may one day be built. The plant could eventually include equipment for siphoning off carbon dioxide. But it's not FutureGen, which today remains a collection of research projects. No FutureGen plant has been constructed, and no site for one has been chosen. The proposed plant at Great Bend could more appropriately be called "PresentGen." The technology involved doesn't demand a White House neologism suggesting that clean coal is something for which we must wait.

Great Bend is owned by American Electric Power (AEP), the largest coal-burning company in the United States. The company proposes to build what's called an integrated gasification combined-cycle (IGCC) plant. IGCC is frequently referred to as a "new technology," but it's really a combination of two well-established technologies—both of which are also intended for FutureGen. The first is gasification, in which coal is partly combusted under carefully controlled temperatures and pressures and turned into a concentrated "syngas" of mainly carbon monoxide and hydrogen. (From syngas, impurities such as sulfur dioxide can readily be removed.) The second is the "combined cycle"—the electricity generation technology already ubiquitous in natural-gas power plants, where turbines are driven both by a stream of gas and by steam produced from waste heat. Most importantly, carbon dioxide can be captured from a gas stream far more easily than from the smokestacks of a conventional coal plant.

IGCC plants are vastly more advanced than today's pulverized-coal plants—which are planned in ever larger numbers around the world—but they're hardly futuristic. "We've done a pretty thorough due diligence on the technology, and we didn't casually come to the conclusion that IGCC was ready," says Robert Powers, AEP's executive vice president for generation. "Gasifiers have been used since the turn of the last century, in a crude sense, and used in the petrochemical industry and refining industry for years. And certainly, on the generating end of the plant, combined-cycle combustion turbines—we own combined-cycle combustion plants now. Each of those pieces is a mature and developed technology."

Indeed, coal gasification, developed about a century ago, has long been the technology of last resort for countries unable to gain access to oil. The Nazis used it to fuel the Luftwaffe; South Africa adopted it during apartheid. In North Dakota, a coal gasification plant went online in the early 1980s after the Arab oil embargo, later began capturing and selling its carbon dioxide for use in oil recovery, and is still humming today.

And AEP is not alone in revisiting the technology. In Pennsylvania, an industrial consortium is proposing a 5,000-barrel-per-day coal-to-liquid plant, using technology from South African gasification giant Sasol. Peabody Energy is talking about a plant in Illinois that would produce natural

JEFF JACOBSON/REDUX

gas from coal. The governor of Montana, Brian Schweitzer, is trying to jump-start a coal-to-liquids industry in his state. Abroad, a few companies are planning "oxyfuels" plants, in which coal is burned in pure oxygen. (The exhaust gases are mainly carbon dioxide and water vapor; water can be condensed and removed, allowing collection of the concentrated carbon dioxide.)

What's lacking is broad action to build such plants in significant numbers. Coal presents the world's single largest opportunity for carbon dioxide mitigation. Coal consumption produces 37 percent of the world's fossil-fuel-related emissions of carbon dioxide, the chief greenhouse gas. While oil consumption produces more—nearly 42 percent—much of that comes from cars, trucks, planes, and other means of transportation for which carbon dioxide capture is practically impossible. In the United States, coal contributes 51 percent of the electricity but 81 percent of the carbon dioxide related to power generation. The technology for cleaner coal plants and carbon dioxide capture exists. But in a story repeated across many energy sectors, little of it is actually being used.

AEP expects the Great Bend IGCC plant to cost 15 to 20 percent more overall than a conventional coal plant, but it could recoup the difference from customers under pending regulation in Ohio and West Virginia (site of a second proposed AEP IGCC plant). Capturing the carbon dioxide emitted by the plant, however, is another story. This part of AEP's site plan is literally a blank space, reserved for some future day when carbon dioxide emissions might be regulated. AEP says it is already deploying its own strategies to cut carbon dioxide emissions by 6 percent. But like the White House, it opposes carbon dioxide limits—on the grounds that the United States shouldn't do anything China and India aren't doing. Yet the technology for carbon capture is mature, too. For years, the Norwegian company Statoil has been capturing and sequestering carbon dioxide produced by its natural-gas wells in the North Sea. And AEP maintains the position that underground sequestration seems feasible in regions it serves.

We're stuck with coal, the most abundant fossil fuel. Cleaner technology exists, and carbon dioxide burial seems feasible. But in a story that's repeated across many energy sectors, little is yet being done.

If IGCC is more than ready, its benefits are apparent, and sequestration seems plausible, why aren't plants that at least make carbon dioxide capture simpler getting built? "I don't necessarily think the technology is the limiting step. What's not there is the economic incentive, of course," says Howard Herzog, a chemical engineer at MIT, who manages an industrial consortium called the Carbon Sequestration Initiative. AEP estimates that IGCC plants with carbon sequestration could carry a 50 percent overall cost premium compared with traditional plants. But IGCC plants are also a little more efficient than traditional plants, and their cost might come down when they're built in volume, or if improved designs and materials boost their efficiency further. Markets might even emerge for carbon dioxide, which can be pumped into oil wells to enhance production. Still, the proliferation of better coal-fired power plants will need kick-starting. "You are not going to do this without some policy changes," Herzog says. "But technology-wise, I think we can do this quickly."

The Coal Menace

Coal supplies 24 percent of all global energy and 40 percent of all electricity, and it spews more carbon than any other fossil source—kilowatt for kilowatt, twice as much as natural gas. Yet coal is the most abundant fossil fuel, and its use is intensifying. While estimates of remaining fossil supplies vary, the World Coal Institute says there are 164 years' worth of coal still in the ground, in contrast to just 41 years' worth of oil. Coal is being enthusiastically mined not only in the United States but also in India and China (where at least 79 percent of electricity comes from coal). The equivalent of more than 1,400 500-megawatt coal power plants are planned worldwide by 2020, according to the Natural Resources Defense Council. This includes 140 U.S. plants of various sizes. "Coal is going to be used. It was a bad joke played by God that oil and gas were put where there is no demand, and coal was put in China, India, and the United States," says Ernest J. Moniz, an MIT physicist and a former undersecretary of the U.S. Department of Energy.

In short, we're stuck with coal. Since there's little reason to expect that humankind will stop digging for it, we will have to find cleaner ways to burn it. This was made clear by a Princeton University analysis that showed immediate ways to reduce carbon dioxide emissions. The analysis goes like this: Already, humankind is pumping about seven billion tons of carbon per year into the atmosphere, about three times as much as in the 1950s, and that figure looks likely to double by 2055. (These tonnages are for carbon; for carbon dioxide, multiply by 3.7.) At that rate, we're on track to triple atmospheric carbon dioxide concentrations from preindustrial levels, creating temperatures not seen since three million years ago, when sea levels were 15 to 35 meters higher *(see "The Messenger," p. 38)*.

But the Princeton group, called the Carbon Mitigation Initiative, showed that it's possible, with today's technologies, to deploy a variety of strategies that would each save one billion tons of carbon emissions per year. Deploy seven over the next 50 years and you've at least stopped the *increase* in carbon emissions. The group calls each billion-ton saving a "wedge." Its report showed that sequestering carbon from 800 coal power plants—or 180 coal-based synfuels plants, which make liquid fuels—would furnish a wedge each. So would tripling nuclear power, doubling automotive efficiency, and implementing the best available energy efficiency technologies in buildings *(see "The Un-Coal," this page)*. "These aren't pipe dreams. These are here today and could be deployed at scale," says Princeton's Robert Socolow, a professor of mechanical engineering and codirector of the Carbon Mitigation Initiative.

But not all wedges are created equal. If we "get the automobiles wrong," says Socolow, it's not an insurmountable problem, because "they are not going to be there 20 years from now. But when we build a power plant—a new one—it's going to be around for 50 or 60 years." And that—along with coal's impending status as the remaining cheap fossil fuel—is why a discussion of wedges very soon becomes a discussion of coal.

The Plug

We still need even better clean coal technology, but when it comes to reducing carbon emissions, the overriding research question is geological. No clean coal technology can forestall climate change without the aid of carbon dioxide sequestration. Unless the carbon dioxide from coal-fired plants is permanently stored somewhere, it will go into the atmosphere and worsen global warming. Sequestration proposals include pumping carbon dioxide underground, pumping it under the sea, and mineralizing it for burial. But significantly reducing carbon emissions while still increasing fossil fuel consumption will require a massive effort: liquid carbon dioxide would have to be sequestered on the same general scale on which the original fossil fuel sources were removed. It's a staggering proposition.

To date, pumping carbon dioxide underground has mainly been a way to push more oil to the surface; the primary objective wasn't really to store carbon dioxide permanently. So a critical question remains unanswered: will carbon dioxide stay where you want it?

In an old steel-walled lab at Los Alamos National Laboratory in New Mexico, geochemist George Guthrie holds out a smooth chunk of cement the size of a sea scallop. The chunk was recently drilled out of cement poured more than 50 years ago to plug the pipe in an old Texas oil well that had been crammed with carbon dioxide to enhance oil recovery. Guthrie holds up the chunk: a quarter-inch swath of it is the

The Un-Coal

By investing in energy efficiency, we could vastly reduce carbon dioxide emissions and save money.

There is a low-tech way to sequester carbon dioxide: don't dig up so much coal and oil in the first place. Princeton University's Carbon Mitigation Initiative concludes that using the most efficient building technologies for commercial and residential buildings could avert as much carbon dioxide as is produced by 800 one-gigawatt coal power plants. Doubling automotive efficiency—possible with existing technology—would achieve the same. Do both and you've canceled out the emissions of 1,600 coal power plants—more than all the coal plants proposed globally today.

Clearly, even partial deployment would yield enormous benefits. So what's the problem? "The classic reason why efficiency didn't fare well [is that] it took five guys in a corporate boardroom to spend a couple billion bucks to build a power plant that can power 250,000 homes," says Steve Selkowitz, who manages building-efficiency research programs at Lawrence Berkeley National Laboratory in Berkeley, CA. "Getting 250,000 homeowners to each change 10 light bulbs and buy a more efficient refrigerator and air conditioner takes much more effort."

And right now, federal policy mostly helps the five guys in the boardroom. Consider federal tax credits and funding for energy-related activities: according to the Alliance to Save Energy, an energy-efficiency organization, most energy tax breaks go to efforts to bolster energy supply, primarily fossil fuels. Only 14 percent go to efforts to increase efficiency and reduce consumption, even though the benefits would be the same or better in terms of cost, and the measures would prevent—rather than add to—carbon dioxide and other emissions.

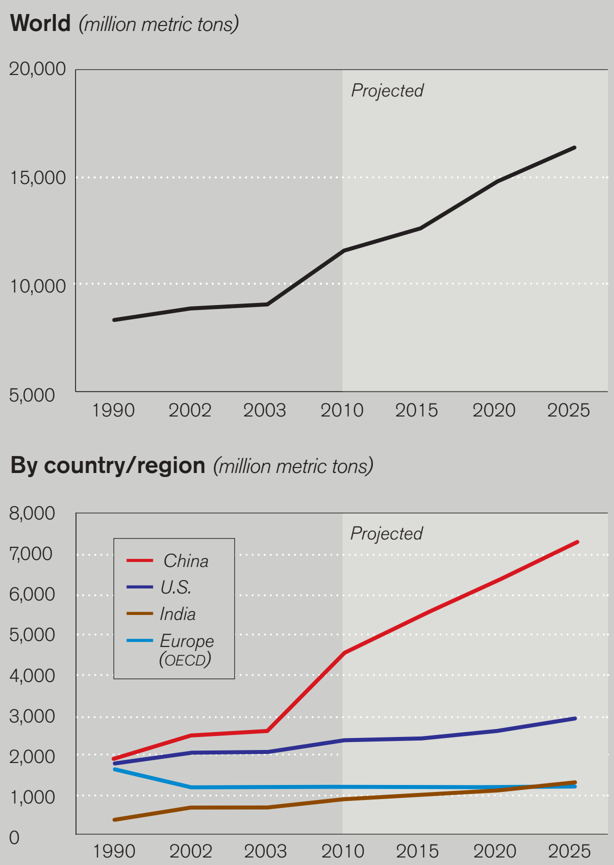
Consider what's possible with lighting alone. Half of U.S. electricity comes from coal. Two-thirds of U.S. electricity is consumed in commercial and residential buildings. In commercial buildings, 35 percent of electricity goes to lighting (the figure is 20 percent for homes). Selkowitz says that with an aggressive effort, lighting consumption in commercial buildings could readily be cut—by half—through better designs, more-efficient light sources, and smart sensor and control systems. That strategy alone, fully deployed, would replace 40 one-gigawatt coal plants.

But are efficiency investments really cost effective? A 2001 National Academies study found that just three small U.S. Energy Department–funded R&D programs that produced technologies now widely deployed—electronic ballasts for fluorescent lamps, efficient refrigerator compressors, and low-emissivity (low-E) coatings for windows—have achieved cumulative energy savings of $30 billion. Despite this lesson—to say nothing of the climate-change issue—the White House wants to cut efficiency efforts further. In its proposed fiscal 2007 budget, research at the Energy Department's Energy Efficiency and Renewable Energy office would get $517 million, down $112 million. Efficiency incentives would get trimmed, too. **DAVID TALBOT**

color of an orange Creamsicle. This staining, Guthrie says, is acid corrosion induced by carbon dioxide, which forms carbonic acid when it mixes with groundwater.

The chunk is a kind of Rorschach test. On the one hand, it could be read to imply that the carbon dioxide damaged the cement plug. On the other hand, it might imply that the damage was minimal—and may not progress further. There's a lot riding on the answer. If the plug on a reservoir blew, the carbon dioxide could be released—and the climate benefits of sequestration would, as it were, vanish

Surging CO_2 Emissions from Coal



Source: U.S. Energy Information Administration

into thin air. "There are significant consequences for doing this wrong," Guthrie observes. "On the other hand, it may be that much of the technology for doing this right already exists. There has been such enthusiasm behind [sequestration] that it is easy to forget about the implications of doing this on such a large scale."

There is reason for guarded optimism. The Statoil project and the Dakota gasification plant have already stored 20 million tons of carbon dioxide each; a gas field in Algeria has stored 17 million tons; a project in the Netherlands, eight million. The U.N.'s Intergovernmental Panel on Climate Change estimates—based on experience and on models—that properly engineered systems could retain 99 percent of their carbon dioxide over 100 years and would "likely" do so over 1,000 years. AEP's Powers, too, seems confident. "If you look at the science, it suggests that our footprint in the U.S. is blessed with the right geologic formations to sequester hundreds of years' worth of CO_2 emissions," he says. "I'm not trying to trivialize the public-policy aspect of this, but you get a picture painted that the geology is there."

What carbon dioxide we can't sequester, or sell to oil companies hoping to use it to force out more oil, we could use to produce alternative fuels. Specifically, it could help make methanol, which could be a more practical fuel than hydrogen. Hydrogen is merely an energy carrier; energy is required to create it in the first place, either by splitting water molecules with electricity or by extracting it from fossil fuels. To make the transition to a "hydrogen economy," not only would you need to produce the hydrogen, but you'd also need an entirely new infrastructure for delivering and storing it, plus vast improvements in fuel cell technology to make it useful.

But if you took hydrogen and combined it with carbon dioxide (which would be, admittedly, another energy-consuming step), you could produce methanol, essentially creating a liquid energy carrier. Unlike hydrogen, methanol could be transported using today's infrastructure and burned in slightly modified versions of today's vehicles. "The president says nice things about moving from a carbon-based economy to a new one. I think it's said easily, but it's not so easily done," says George Olah, a Nobel laureate in chemistry and director of the Loker Hydrocarbon Research Institute at the University of Southern California. Olah is an active proponent of the "methanol economy": "What I'm saying is that we have the basis of carbon dioxide that can be recycled," he says.

Carbon's Price

After President Bush told the nation it was addicted to oil in the State of the Union address this year, he reeled off several clean-energy research ideas and said we were "on the threshold of incredible advances." The implication seemed to be that we need these "incredible advances" before we can really get serious about replacing fossil fuels or dealing with climate concerns.

The reality is that we already have several good technological options. The question remains one of policy. No energy company will reduce carbon dioxide emissions unless carbon dioxide has a cost. But because emissions are a classic example of what economists call a "negative externality," where the cost of a thing is not borne by the parties involved in a transaction (here, energy producers and buyers), the government must impose that cost through regulation. One

SHERYL MENEZ/WPN

GREENHOUSE HAZE **Smog in Shanghai results from the burning of low-grade coal. Chinese coal consumption is rising sharply.**

approach would be a "cap and trade" system—used successfully for sulfur dioxide—in which an overall limit is set on emissions from all regulated sources. Companies work out where best to cut emissions, then trade emissions credits in order to stay under the collective national "cap," which can be gradually lowered as cleaner technologies emerge.

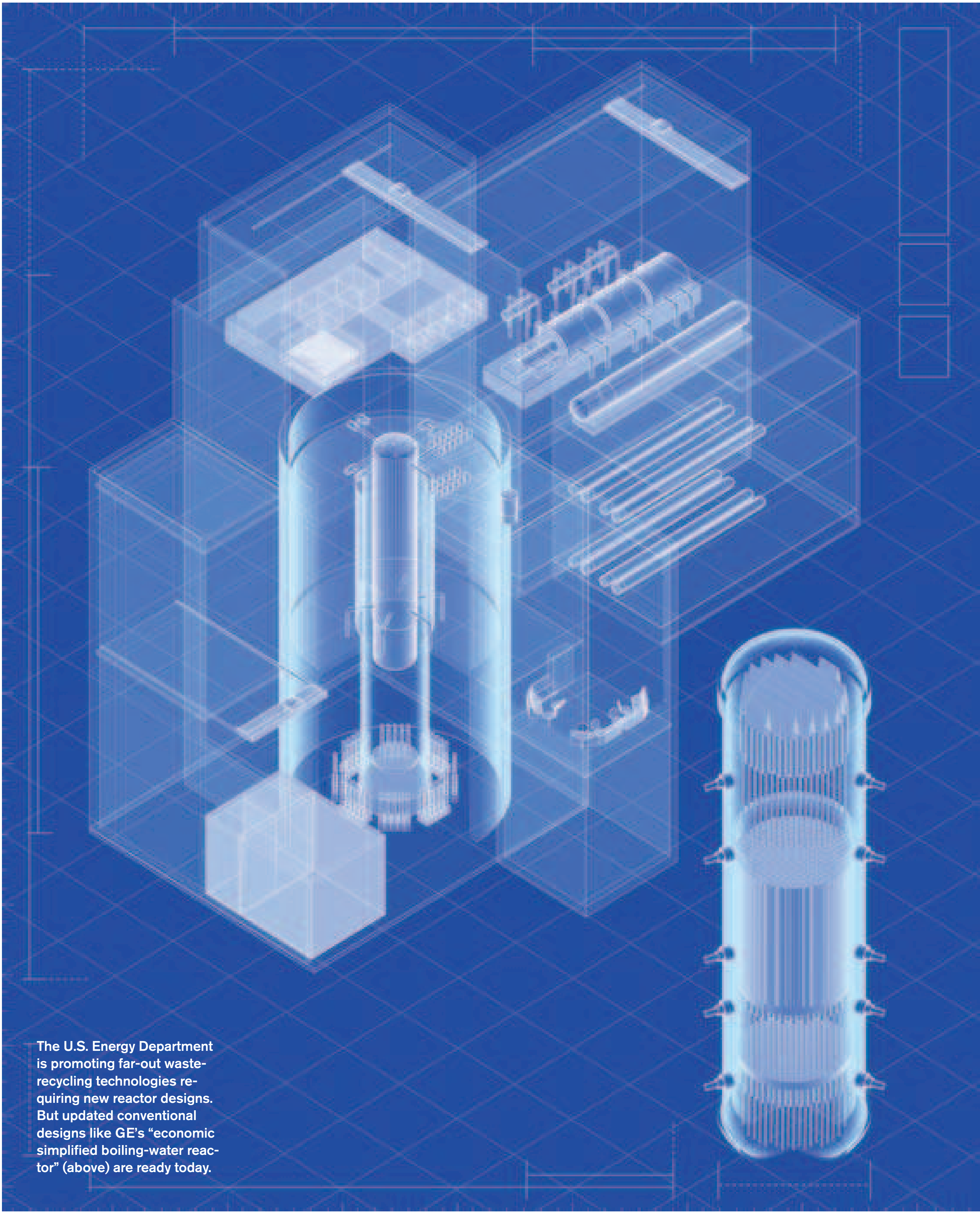
The first halting steps toward carbon dioxide regulation are being taken. California has moved to limit greenhouse-gas emissions from vehicles—but is facing court challenges from the auto industry. And the European Union has launched a carbon-trading system, now in its initial phase *(see "Rocky Start for CO_2 Trading," p. 18)*. But in the U.S., there is little imminent likelihood that carbon dioxide emissions from vehicles or power plants will be federally regulated.

In the summer of 2006, there is good reason to think that technology available today can significantly mitigate the carbon dioxide problem. But the technology is not enough. "People think you can do this without the policy, and that's a myth," says Herzog of MIT. Without public policy that imposes a cost on carbon emissions, he points out, "it's always going to be cheaper to put it in the atmosphere than to do capture and storage." Still, he and Socolow believe that regulatory help may be on the way. "We are at the point where some carbon dioxide policy is going to come out," Socolow says.

In Great Bend, AEP is preparing for a possible new regulatory climate. It sees clean coal technology as more than ready—in this case, combined-cycle power plants from GE married to gasification technology purchased from Chevron. But without a policy incentive, AEP will not do any carbon dioxide sequestering. As the world digs for more coal, and the atmospheric concentrations of carbon dioxide inexorably rise, the part of the Great Bend plant that would capture and store carbon dioxide—forming a key wedge against worsening climate change—remains an empty space on an engineer's drawing. TR

David Talbot is Technology Review*'s chief correspondent.*

Even if clean coal technology begins to take hold, however, it will not be enough by itself. Besides cleaner ways to burn fossil fuels, …



The U.S. Energy Department is promoting far-out waste-recycling technologies requiring new reactor designs. But updated conventional designs like GE's "economic simplified boiling-water reactor" (above) are ready today.

…we need new carbon-free nuclear power plants that take advantage of the technological advances of the last 40 years. We cannot pin our hopes on nuclear-energy research that may never bear fruit.

The Best Nuclear Option

By **Matthew L. Wald** Illustration by Bryan Christie

Imagine a nuclear industry that can power America for decades using its own radioactive garbage, burning up the parts of today's reactor wastes that are the hardest to dispose of. Add technology that takes nuclear chaff, uranium that was mined and processed but was mostly unusable, and converts it to still more fuel. Then add a global business model that makes it much less likely that reactor by-products such as plutonium will find their way into nuclear weapons in countries like Iran, even as economical nuclear-power technology becomes available to the whole world.

That is the alluring triple play the Bush administration hopes to turn with the Global Nuclear Energy Partnership (GNEP) it unveiled earlier this year, a proposed long-term research and development program almost as audacious as the Manhattan Project. The basic fuel-reprocessing concepts at its heart have been kicking around for the better part of a half-century. Now they are being touted anew as a way to provide plentiful carbon-free fuel for an energy-hungry world threatened by human-induced climate change.

Under the plan, for which the administration has requested $250 million for the fiscal year beginning October 1, the United States and certain partner countries would process spent nuclear fuel using new techniques that would turn some of it into more fuel and minimize the amount requiring disposal. The United States and its partners would also lease reactor fuel to other countries, which would then return their spent fuel to be reprocessed.

The technology could exploit uranium far more efficiently: Phillip J. Finck, associate director at Argonne National Laboratory near Chicago, says it could extract up to 100 times as much energy from uranium as is now possible. With the waste now piled up at reactors around the United States, the theory goes, GNEP could produce all the electricity the country will need for decades, maybe even centuries—assuming enough of the necessary new reactors could be built. That would eliminate about a third of all U.S. carbon dioxide emissions (roughly the portion that today comes from fossil-fuel power plants). All this while reducing waste and thwarting the diversion of fuel to nuclear weapons.

In practice, though, in the best scenario GNEP would take decades to develop, and in the worst it might produce nothing; it could turn out to be a nonstarter on technical grounds, or the technology could be economically uncompetitive with other carbon-free sources of electricity. And the program could undermine a more modest and achievable goal: resuscitating a nuclear industry that hasn't launched a successful reactor project since 1974.

Today, a public once wary of nuclear energy has opened up to it as a possible answer to global warming. New reactor designs similar to those used in today's commercial fleet—but said to be safer and more efficient—are already approved or under review by the U.S. Nuclear Regulatory Commission. Utilities are in various stages of planning at least 16 such reactors *(see "Stirrings of Renewal," p. 61)* and may file applications with the NRC as early as the end of next year.

Such reactors are the most promising near-term alternative to additional conventional coal plants that produce prodigious amounts of carbon dioxide. But it is uncertain when or if they will be built. If it is to happen, the industry must persuade investors to take a big plunge. That means con-

vincing them that the plants will compete financially with other inherently low-carbon-emitting sources, like wind turbines, or with coal plants that sequester their carbon dioxide—a technology that may be achievable but hasn't yet been demonstrated *(see "The Dirty Secret," p. 52)*. According to the Electric Power Research Institute (EPRI), a nonprofit utility research organization based in Palo Alto, CA, whose members include owners of coal and nuclear plants, the near-term reactor designs may barely be cheaper than the sequestration technology. And if the United States puts no constraints on carbon emissions, nuclear power will have to keep competing with conventional coal plants.

Meanwhile, the industry is still waiting for a solution to its chief near-term problem: what to do with waste piling up at existing nuclear plants. Skip Bowman, president and CEO of the Nuclear Energy Institute, the industry's trade group, says that without a speedy waste solution, today's tentative renaissance will "come to a screeching halt." A company cannot get a license for a new plant without a plan for the waste, and at this point, waiting for the Energy Department to open its long-delayed Yucca Mountain waste repository in Nevada does not constitute a plan. In this context, Bowman says, GNEP presents a "distraction factor."

The U.S. Energy Department's fuel-recycling initiative could be a distraction from a more achievable goal: reviving today's nuclear industry and averting some carbon emissions in the short term.

Some academics agree, saying the Energy Department needs to forge a clear nuclear strategy and stick with it. Andrew Kadak, a nuclear engineer at MIT *(see "DOE's Blurred Nuclear Vision," p. 26)*, says the department has followed "zigzag policies." He counts GNEP as the fifth nuclear initiative in the last five years, citing the Nuclear Hydrogen Initiative; Nuclear Power 2010 (an effort to break ground on a new conventional reactor by that year); Generation IV (a new suite of reactor technologies, such as gas-cooled or lead-cooled plants); and the Advanced Fuel Cycle Initiative, which portions of GNEP resemble.

If the Energy Department wants to reduce carbon dioxide emissions by promoting the promised revival of nuclear energy, it will have to hurry before power companies fill the market with conventional coal plants that could last 50 years. GNEP may only weaken the department's focus, adding cost and complexity with new, untried technologies.

Fast Reactors, Slow Progress

GNEP is a very long-term vision; most of the initial $250 million would be spent just to study how the new technologies might work and what they would cost. But its proponents' thinking is that we *need* a very long-term vision. The Energy Department predicts that 1,000 nuclear power plants will be running worldwide by midcentury, up from 441 today. And the existing uranium supply, GNEP advocates argue, won't feed that many reactors.

The size of the uranium supply is in fact unknown, because uranium went through a long period of depressed prices, and not many people have been looking for it lately. According to industry sources, about 3 million tons are known to exist, but another 12 million tons or so may be out there. (An MIT study in 2003 predicted that enough uranium was still available to build 1,000 reactors and run them for 40 years.) To the extent that we may need to stretch this resource, however, GNEP offers a way—at least on paper—to recover vast amounts of additional energy from it.

Existing reactors generate energy through a chain reaction that begins when a free neutron hits an atom of U-235, an isotope of uranium, and splits its nucleus. The split atom throws off two or three neutrons; usually, one splits another U-235 atom, and others are absorbed by atoms of another uranium isotope, U-238, to form plutonium-239 and other transuranic elements (those beyond uranium in the periodic table). These transuranics, along with fission products such as cesium isotopes, are among the components of nuclear waste.

The trouble is, U-235 is a relatively rare isotope; natural uranium consists of about one part U-235 to 142 parts U-238, which is not as easily split. Uranium used for reactors is enriched so that U-235 occurs at a concentration of one part in 20. GNEP would use uranium more efficiently by burning transuranics from spent fuel, after they are separated from the other byproducts through reprocessing. It could also exploit some of the U-238. The key would be to develop a new generation of reactors, called "fast reactors."

Reactors that are cooled by water, as almost all reactors are today, slow the neutrons considerably after they're released by the chain reaction. But the reactors proposed by GNEP would not; they would use a different material, probably molten metal, to carry off the heat. (Unfortunately, the preferred metal for this purpose—sodium—burns on contact with water or air.) Like a billiard ball shot by a more powerful cue, the neutrons would pack a bigger punch—enough to split some of the U-238 as well as the transuranic isotopes.

The transuranics happen to be among the longest-lived materials in the waste stream, and thus some of the hardest to dispose of. That's what makes GNEP seem so appealing as not only a climate-change solution but a waste solu-

Stirrings of Renewal *(Announced locations for proposed new nuclear power plants, as of April. Noneare certain to be built.)*

Company/(Consortium)	Number of Units/Plant Sites	Application Possible
Dominion	1/North Anna, VA	2007
Duke	2/Cherokee, SC	2007
Entergy	2/River Bend, LA, and Grand Gulf, MS (NuStart)	2007/2008
Exelon	Not determined/Clinton, IL	Not available
TVA/(NuStart)	2/Bellefonte, AL	2007
Progress Energy	4/Harris, NC, and a site in Florida	2007/2008
SC Electric & Gas	2/Summer, SC	2007
Southern Co.	2/Vogtle, GA	2008
Constellation/(UniStar)	1/Calvert Cliffs, MD, or Nine Mile Point, NY	2008

tion, too. Finck says it would theoretically cut the heat and toxicity of what is today considered waste enough to make Yucca Mountain last through this century, instead of being fully booked before the first fuel bundle is buried.

Nuclear-power pioneers in industry and government always assumed that fuel would be reprocessed to recover the plutonium for reuse. Such reprocessing is the way the Manhattan Project gathered plutonium for the bomb that destroyed Nagasaki. (The Hiroshima bomb used enriched uranium.) W. R. Grace opened a reprocessing center in West Valley, NY, in 1965 and later sold it to Getty Oil. The plant ran until 1972 and cost more than $1.6 billion to clean up. General Electric tried, too, building a plant in Morris, IL, but it was deemed inoperable in 1974. Then President Carter banned the technology because of proliferation concerns.

GNEP would bring these ideas back from the grave in a much more ambitious form that raises such concerns once more. One worry is the way the bomb-usable material would be extracted from the used fuel. Backers say GNEP would reduce the risk of proliferation, because unlike the old reprocessing techniques, still used in some countries, the new ones would not yield pure plutonium. But today eight kilograms of plutonium—the amount required to make a bomb—is embedded in about a metric ton of highly radioactive waste; in the new system it would be diluted with only a small quantity of other materials. Governments or terrorists would find it far easier to steal the separated material and extract the plutonium, critics say, than they would to recover plutonium from today's spent nuclear fuel.

Energy Secretary Samuel Bodman, discussing GNEP, promised that it would "respond to the challenges of global terrorism." The idea is to baby-proof the fuel cycle: countries like Iran could lease fuel enriched to reactor levels—5 percent U-235—but not to bomb levels, typically greater than 90 percent U-235. They would send their spent fuel back to more-secure countries for reprocessing and a second go-round inside the advanced reactors. These reactors, which would burn many of the elements produced in the simpler reactors, would be located in stable places like Indiana or Florida—or in countries that already have nuclear weapons.

The resulting "partnership" would make American policy on nuclear technology more similar to that of Russia and France, both of which already separate plutonium. Advocates cite this as an added bonus of a program that, says Finck, "will provide the United States with a long-term, affordable, carbon-free energy source with low environmental impact."

The GNEP Mirage

But GNEP may be a mirage. For one thing, the sponsors have hardly any idea what it would cost; the $250 million proposed by the Bush administration is for a program that hopes to figure that out. GNEP backers say their technology will expand the supply of nuclear fuel enough to slash carbon emissions virtually forever and allow us to avoid the specter of choosing between global warming and very high-priced energy. It would appear, however, that saving money on nuclear fuel may be practical only if price is no object.

Richard L. Garwin, an IBM fellow emeritus and the coauthor of seven books on nuclear weapons and nuclear power, estimates that existing reprocessing plants like the one operating in France supply reactors with plutonium at a price of approximately $1,000 per kilogram of uranium saved. But the market price of uranium, he points out, is around $100 per kilogram, and it might be at a temporary peak.

Fuel is only part of the cost of nuclear power, and Finck says reprocessing fuel and reusing it in fast reactors would add only about 10 percent to overall power costs. But where even that modest increment would come from is not clear. Frank N. von Hippel, a physicist and policy expert at Princeton University's Woodrow Wilson School of Public and International Affairs, notes that the United States set out to build a fast reactor in the 1970s but dropped the effort in

1983 after France, Germany, and the United Kingdom built them and then abandoned them as too costly and difficult. And once the fast reactors were built, the system envisioned by GNEP might require as many as one of the expensive new reactors for every three ordinary ones, according to sponsors, depending on how effective the new reactors were. Garwin says of the fast reactors, "There is no conception of these things making their way economically."

"I hope that we'll have more reactors; I certainly hope the world will have more," Garwin says, referring to the types that are operating commercially today. "But that will only happen if it looks economically profitable for private industry to get into this area." And right now a lot of smart money—some of it channeled through the Energy Department—is going not only into that conventional nuclear power but also into other carbon-free energy sources, such as wind, solar, and coal with carbon dioxide sequestration.

EPRI recently analyzed the prices of zero-carbon electricity sources and found that if, as manufacturers claim, new reactors could be built for $1,700 per kilowatt of capacity (less than the cost in the 1980s, even before adjusting for inflation), they would produce electricity at about $49 per megawatt-hour. Although that's about two-thirds the price of biomass, and half the price of wind, other technologies on the drawing board may do the job for very little more. For about $55 per megawatt-hour, EPRI found, coal could be gasified and burned, and the carbon dioxide sequestered. Power plants running on gasified coal have not been commercialized yet, but conventional pulverized-coal plants could be built that would sequester their carbon dioxide, and they would produce power at about $65 per megawatt-hour. Those technologies are perceived by investors as lower risk, and the United States has hundreds of years' worth of coal.

In a few years, or a few decades, carbon taxes could be universal in the industrial world, a war in the Persian Gulf could make the price of oil double or triple, and electricity demand could surge—particularly if somebody came up with a better battery that could be mass-produced for electric cars. But even if all those things pushed the world toward zero-carbon energy, we would still be looking for the zero-carbon energy that cost least. That could be nuclear energy, according to EPRI. But Steve Specker, the president of EPRI, expects a "horse race" between different zero-carbon coal technologies.

Playing with Proliferation

Beyond the cost issue, GNEP could reverse a successful strategy against proliferation, say a variety of scientists, including Princeton's von Hippel. He argues that reprocessing spent nuclear fuel creates too great a risk, even if the plutonium is mixed with small amounts of other materials that do not make good bomb fuel. Not only could plutonium from spent fuel fall into the wrong hands, opponents say, but reprocessing in the United States could encourage other countries to reprocess nuclear waste themselves, making their own by-products available for weapons.

Given that the United States gave up reprocessing in the mid-1970s for that very reason, von Hippel finds it ominous that now, with GNEP, the country could embrace it once more. "The United States has been extraordinarily successful for 30 years in opposing the spread of reprocessing to non-weapons states by making the argument 'We don't reprocess; you don't need to either,'" he says. That's part of the logic of the 2003 MIT study, "The Future of Nuclear Power," which concluded that reprocessing as pursued by France, Russia, and Japan did not provide sufficient safeguards against proliferation. It also concluded that the prospect of a uranium shortage wouldn't be a reason to move to reprocessing in the United States "for many years to come."

It's easy to see why the research community is delighted about GNEP. It represents a huge source of funds. It's a loaves-and-fishes trick for the industrializing world, especially for bureaucrats who would like to redeem the predictions, made by their 1950s predecessors, of power "too cheap to meter." But GNEP is not relevant to a revival of nuclear power. Utilities abandoned more than 100 reactor projects in the 1970s and '80s, and only now—spurred by high fossil-fuel prices and a shift in public attitudes—are they thinking of trying again. A fancy fuel cycle meant to support a burgeoning commercial industry is useless if there is no commercial industry. What nuclear power needs is to get up and running soon, supplanting carbon-dioxide-emitting sources in an economical and boring way. Without that, nothing will follow. TR

Matthew L. Wald, a reporter in the Washington bureau of the New York Times, *has written about the nuclear industry for 27 years.*

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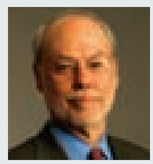

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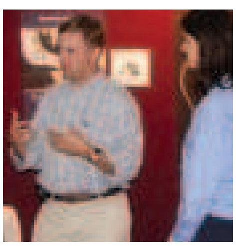

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…could be ethanol. Genetically engineered microörganisms that more efficiently produce ethanol from cheap and abundant sources of biomass, such as agricultural waste, could make it cost competitive.

Redesigning Life to Make Ethanol

By Jamie Shreeve

On January 31, Ari Patrinos was sitting in his living room in Rockville, MD, listening to the State of the Union speech and slowly nodding off. Suddenly, he was jolted awake.

"We'll also fund additional research for cutting-edge methods of producing ethanol," President Bush was saying on the television, "not just from corn but from wood chips and stalks or switchgrass. Our goal is to make this new kind of ethanol practical and competitive within six years."

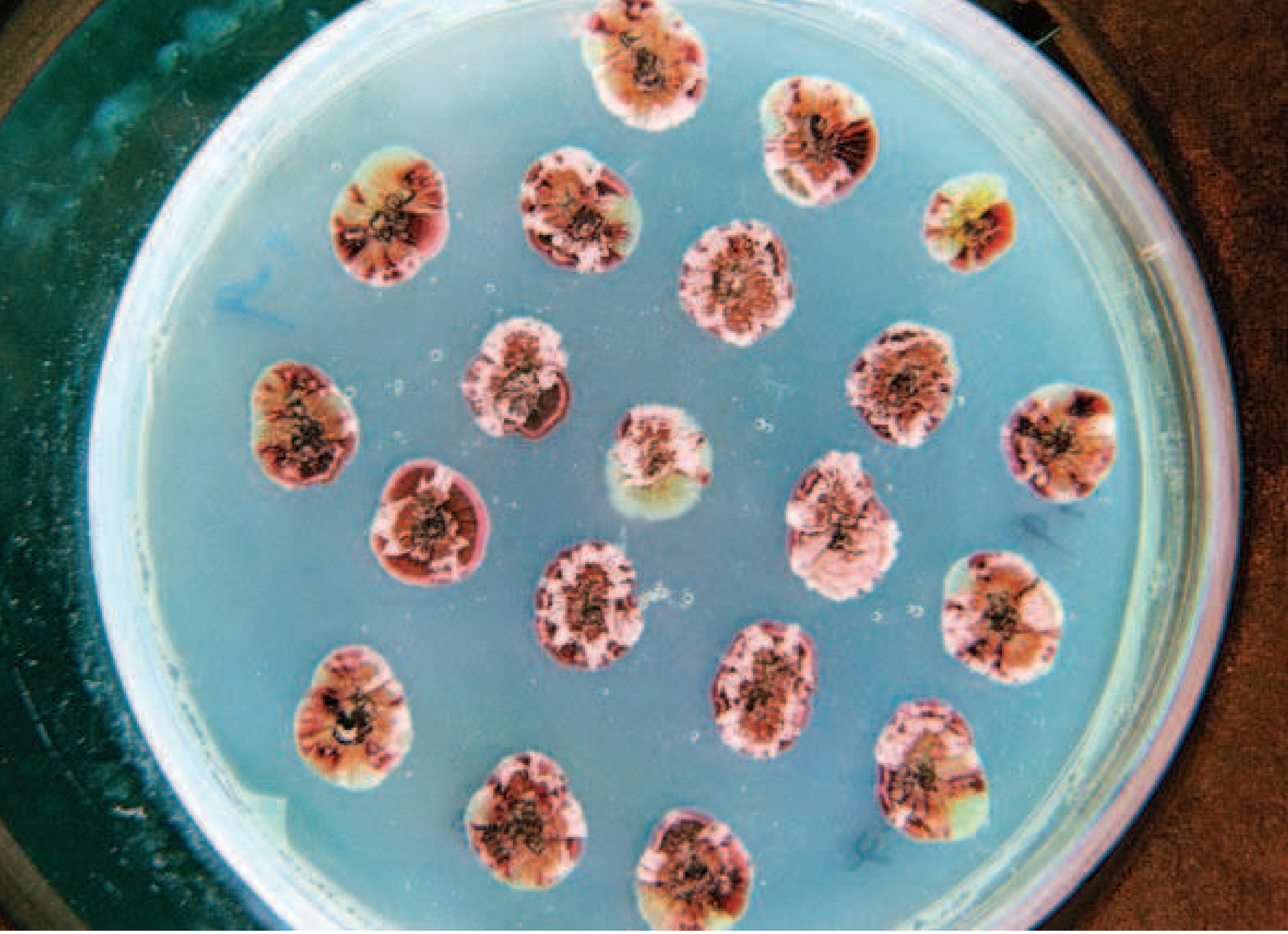
Unlike most of the legislators who gamely applauded the president's words, Patrinos understood exactly what they meant. In fact, he had dashed them off himself days earlier at the harried request of his boss, unaware that they were destined for the State of the Union speech. Patrinos, then associate director of the U.S. Department of Energy's Office of Biological and Environmental Research, had been touting cellulosic ethanol as an alternative energy source for years, only to be met with indifference or ridicule. Now, it seemed, even the most petro-friendly of politicians was convinced.

Producing ethanol fuel from biomass is attractive for a number of reasons. At a time of soaring gas prices and worries over the long-term availability of foreign oil, the domestic supply of raw materials for making biofuels appears nearly unlimited. Meanwhile, the amount of carbon dioxide dumped into the atmosphere annually by burning fossil fuels is projected to rise worldwide from about 24 billion metric tons in 2002 to 33 billion metric tons in 2015. Burning a gallon of ethanol, on the other hand, adds little to the total carbon in the atmosphere, since the carbon dioxide given off in the process is roughly equal to the amount absorbed by the plants used to produce the next gallon.

Using ethanol for auto fuel is hardly a new idea *(see "Brazil's Bounty," p. 28)*. Since the energy crisis of the early 1970s, tax incentives have pushed ethanol production up; in 2005, it reached four billion gallons a year. But that still translates to only 3 percent of the fuel in American gas tanks. One reason for the limited use of ethanol is that in the United States, it's made almost exclusively from cornstarch; the process is inefficient and competes with other agricultural uses of corn. While it is relatively easy to convert the starch in corn kernels into the sugars needed to produce ethanol, the fuel yield is low compared with the amount of energy that goes into raising and harvesting the crops. Processing ethanol from cellulose—wheat and rice straw, switchgrass, paper pulp, agricultural waste products like corn cobs and leaves—has the potential to squeeze at least twice as much fuel from the same area of land, because so much more biomass is available per acre. Moreover, such an approach would use feedstocks that are otherwise essentially worthless.

Converting cellulose to ethanol involves two fundamental steps: breaking the long chains of cellulose molecules into glucose and other sugars, and fermenting those sugars into ethanol. In nature, these processes are performed by different organisms: fungi and bacteria that use enzymes (cellulases) to "free" the sugar in cellulose, and other microbes, primarily yeasts, that ferment sugars into alcohol.

In 2004, Iogen, a Canadian biotechnology company based in Ottawa, began selling modest amounts of cellulosic etha-



nol, made using common wheat straw as feedstock and a tropical fungus genetically enhanced to hyperproduce its cellulose-digesting enzymes. But Iogen estimates that its first full-scale commercial plant, for which it hopes to break ground in 2007, will cost $300 million—five times the cost of a conventional corn-fed ethanol facility of similar size.

The more one can fiddle with the ethanol-producing microbes to reduce the number of steps in the conversion process, the lower costs will be, and the sooner cellulosic ethanol will become commercially competitive. In conventional production, for instance, ethanol has to be continually removed from fermentation reactors, because the yeasts cannot tolerate too much of it. MIT's Greg Stephanopoulos, a professor of chemical engineering, has developed a yeast that can tolerate 50 percent more ethanol. But, he says, such genetic engineering involves more than just splicing in a gene or two. "The question isn't whether we can make an organism that makes ethanol," says Stephanopoulos. "It's how we can engineer a whole network of reactions to convert different sugars into ethanol at high yields and productivities. Ethanol tolerance is a property of the system, not a single gene. If we want to increase the overall yield, we have to manipulate many genes at the same time."

NREL/U.S. DEPARTMENT OF ENERGY/PHOTO RESEARCHERS, INC.

BIOFUEL BUGS Colonies of recombinant *Streptomyces* bacteria from the National Renewable Energy Laboratory are designed to produce enzymes called cellulases. With these enzymes, the bacteria can break down cellulose on the way to producing ethanol.

The ideal organism would do it all—break down cellulose like a bacterium, ferment sugar like a yeast, tolerate high concentrations of ethanol, and devote most of its metabolic resources to producing just ethanol. There are two strategies for creating such an all-purpose bug. One is to modify an existing microbe by adding desired genetic pathways from other organisms and "knocking out" undesirable ones; the other is to start with the clean slate of a stripped-down synthetic cell and build a custom genome almost from scratch.

Lee Lynd, an engineering professor at Dartmouth University, is betting on the first approach. He and his colleagues want to collapse the many biologically mediated steps involved in ethanol production into one. "This is a potentially game-changing breakthrough in low-cost processing of cellulosic biomass," he says. The strategy could involve either modifying an organism that naturally metabolizes cellulose so that it produces high yields of ethanol, or engineering a natural ethanol producer so that it metabolizes cellulose.

This May, Lynd and his colleagues reported advances on both fronts. A team from the University of Stellenbosch in South Africa that had collaborated with Lynd announced that it had designed a yeast that can survive on cellulose alone, breaking down the complex molecules and fermenting the resultant simple sugars into ethanol. At the same time, Lynd's group reported engineering a "thermophilic" bacterium—one that naturally lives in high-temperature environments—whose only fermentation product is ethanol. Other organisms have been engineered to perform similar sleights of hand at normal temperatures, but Lynd's recombinant microbe does so at the high temperatures where commercial cellulases work best. "We're much closer to commercial use than people think," says Lynd, who is commercializing advanced ethanol technology at Mascoma, a startup in Cambridge, MA.

Others are pursuing a far more radical approach. Soon after the State of the Union speech, Patrinos left the DOE to become president of Synthetic Genomics, a startup in Rockville, MD, founded by Craig Venter, the iconoclastic biologist who led the private effort to decode the human genome. Synthetic Genomics is in hot pursuit of a bacterium "that will do everything," as Venter puts it. With funding from Synthetic Genomics, scientists at the J. Craig Venter Institute are adding and subtracting genes from natural organisms using the recombinant techniques employed by other microbial engineers. In the long run, however, Venter is counting on an approach more in keeping with his reputation as a trailblazer. Rather than modify existing organisms to produce ethanol and other potential biofuels, he wants to build new ones.

Natural selection, argues Venter, does not design life forms to efficiently perform the multitudinous functions their genes encode, much less to carry out a dedicated task like ethanol production. Consequently, a huge amount of effort and expense goes toward figuring out how to shut down complex, often redundant genetic pathways that billions of years of evolution have etched into organisms. Why not start with a genome that has only the minimal number of genes needed to sustain life and add to it what you need? "With a synthetic cell, you only have the pathways in there that you want to be in there," he says.

Synthetic Genomics' approach is based on research that Venter's Institute for Genomic Research conducted on a microörganism called *Mycoplasma genitalium* in the late 1990s. The microbe, which dwells in the human urinary tract, has only 517 genes. While that's the smallest genome seen in any life form known, researchers in Venter's group showed that the organism could survive even after they had knocked out almost half of its protein-coding genes (some genes code not for proteins but for other biomolecules that perform regulatory functions within the cell). Using the DNA sequence of this "minimal genome" as a guide, they are now attempting to synthesize an artificial chromosome that, inserted into a hollowed-out cell, will lead to a viable life form. Once they are over this first hurdle, they plan to build synthesized, task-specific genetic pathways into the genome, much the way one might load software onto a computer's operating system. Rather than create spreadsheets or do word processing, however, such "biologically based software" would instruct the cell to break down cellulose to produce ethanol or carry out other useful functions. "This is a totally new field on the verge of explosion," says Venter.

Among biofuels, ethanol is the established front-runner, but various types of microbes also produce hydrogen, methane, biodiesel, and even electricity—which means they could be genetically engineered to produce more of these resources. At the University of California, Berkeley, bioengineer Jay Keasling and his colleagues are proposing to design organisms that pump out a fuel no natural microbe makes, one that offers some alluring advantages over ethanol: gasoline. Its virtues as a fuel are proven, of course, and the ability to produce it from waste wood and waste paper, which Keasling thinks is feasible, could reduce countries' dependence on foreign oil. And unlike ethanol, which is water soluble and must be transported in trucks lest it pick up water in pipes, biologically generated octane could be economically piped to consumers, just like today's gas.

"Ethanol has a place, but it's probably not the best fuel in the long term," says Keasling. "People have been using it for a long time to make wine and beer. But there's no reason we have to settle for a 5,000-year-old fuel."

In the short term, some advances in biology and engineering are needed before fuels made from biomass will be practical and competitive with fossil fuels. But in the longer term, says Venter, "we're limited mostly by our imagination, not by the limits of biology." TR

Jamie Shreeve's most recent book is The Genome War.

Ultimately, the world will need to get most of its energy from renewable sources. Besides biomass, a number of other promising candidates exist. But as the demand for energy increases, we also need…

…a long-term strategy to create truly disruptive energy alternatives.

It's Not Too Early

By Marty Hoffert

In the 1970s, Buckminster Fuller proposed superconducting global-scale electrical grids to wheel solar energy collected on the daylight hemisphere halfway around the earth to the nighttime hemisphere.

Given the potential for catastrophic climate change, a question must be asked: What has happened to such far-out and disruptive—but not necessarily unfeasible—visions for a renewable-energy future? Right now, hundreds of new coal plants are on drawing boards around the world *(see "The Dirty Secret," p. 52)*.

Today, the world uses about 13 terawatts of power, approximately 80 percent of it from carbon-dioxide-emitting fossil fuels. If we want to keep Earth's average temperature low enough to prevent eventual large sea-level rises *(see "The Messenger," p. 38)*—and also accommodate continued 3 percent annual economic growth—we will need between 10 and 30 terawatts of new carbon-free power by 2050.

The time to start building a sustainable carbon-free energy infrastructure is now. We need Apollo-type research to accomplish this, beginning perhaps with funding of far-out programs along the lines of ARPA-E ("E" for energy), an initiative proposed by the National Academy of Sciences and modeled on the U.S. Advanced Research Projects Agency (now prefaced by "Defense"), which gave us the Internet.

A global-energy-systems engineer—if such a profession existed—would probably have recourse to many technologies that are disruptive of today's powerful coal, oil, and gas industries. Wind turbines are already economically competitive with conventional energy sources in some regions. Steadier and faster high-altitude winds might be harvested someday by flying wind turbines that transmit electricity to Earth through tethering wires.

The greatest potential for terawatt-scale renewable electric power lies in harvesting solar energy directly. About 2,000 megawatts of silicon-based photovoltaic cells have been manufactured, but the existing technology is expensive. A promising path to cost reduction is thin-film cells that include materials like copper indium diselenide, cadmium telluride, and amorphous silicon. Aggressive R&D and expanding markets will reduce costs, but a big push from government could help realize solar's vast potential.

One weakness of solar power is its intermittency. But photovoltaic panels in geostationary orbit could be positioned to receive constant sunlight and thereby furnish the earth with a reliable stream of electricity. They should be the focus of experiments on the scale of the International Thermonuclear Experimental Reactor scheduled to be built in France. Unlike fusion, space-solar technologies—including wireless power transmission—are well understood. The aesthetics, like those of offshore wind turbines, are contentious. But for me, the image of a ring of sun-reflecting solar-power satellites in the night sky evokes Yeats's "golden apples of the sun"—humankind's coming of age on star power. On Earth, we need entirely new electrical grids that are "smart," store excess power, and minimize resistance to enable transmission of renewable but intermittent energy across continents.

There's much more that can be done to promote "green" homes and offices through a more enlightened federal policy. Mass public exhibits of creative sun- and wind-powered technology, buildings, and communities could stimulate consumer demand in the way that General Motors' "Futurama" exhibit at the 1939 World's Fair created demand for cars and parkways and, by extension, suburban homes.

The late Nobel laureate Rick Smalley observed that even though our civilization has many problems, energy is central to all of them. Questions that begin "What is…?" are often the wrong ones; the better question is "What could possibly be?" Spurred by World War II, the United States went from biplanes to jets, from laboratory U-235 fission to Hiroshima, from microwaves to radar—all in less than a decade. The coming battle for a sustainable energy infrastructure will require every bit as much a team effort from government, researchers, and industry. We know where we must go eventually. Why not head there now? TR

Marty Hoffert is professor emeritus of physics at New York University.

Seeing Your Pain

Learning to consciously alter brain activity through MRI feedback could help control chronic pain and other disorders.

By Emily Singer

I'm lying in the plastic cocoon of an MRI machine, an instrument that measures activity in different parts of the brain. As I try to hold still, the loudly clanking machine runs a structural scan to locate the anterior cingulate cortex and the insula, regions involved in processing pain. A computer then translates the MRI signal into three small animated fires, representing the activity levels of the cingulate and the right and left insula, projected onto a screen above my face.

I concentrate to make those fires roar and ebb, using only my thoughts. As I do, the MRI is measuring changes in the blood flow to selected parts of my brain. The patterns of blood flow tell the computer how neural activity is changing. By trying to control the size of the fires, I am attempting to control brain activity in the cingulate and insula, and in turn to quell the chronic back pain that has irked me in recent years.

Monitoring my progress is Christopher deCharms, a neuroscientist and founder of Omneuron, a startup company in Menlo Park, CA. DeCharms has spent the last five years developing imaging techniques that can be used to teach patients to control their brain activity. Changes in neural activity usually take place unconsciously, as different parts of the brain are engaged to perform tasks or process stimuli. Neurons in the language circuit start firing, for example, when you have a conversation with a friend. When you watch a scary movie, neurons in the amygdala, an area involved in emotion, fire more frequently. But consciously controlling these changes—damping activity in specific brain regions—could theoretically be useful for treating not only pain but such diseases as depression or even stroke. Exerting that kind of control is difficult, but it may offer an alternative to drugs that is both more precise and less likely to cause side effects.

Until a few years ago, selective control of brain activity was just a provocative idea. But a new version of functional magnetic resonance imaging (fMRI) has, for the first time, made brain activity visible in real time. The technology was just what deCharms needed. He and his collaborator Sean Mackey, associate director of the Pain Management Division at Stanford University, have already shown that their technique works, at least in the short term. In December, they published the results of their first study in the journal *Proceedings of the National Academy of Sciences*, showing that both healthy subjects and chronic-pain patients could learn to control brain activity—and pain—using real-time fMRI.

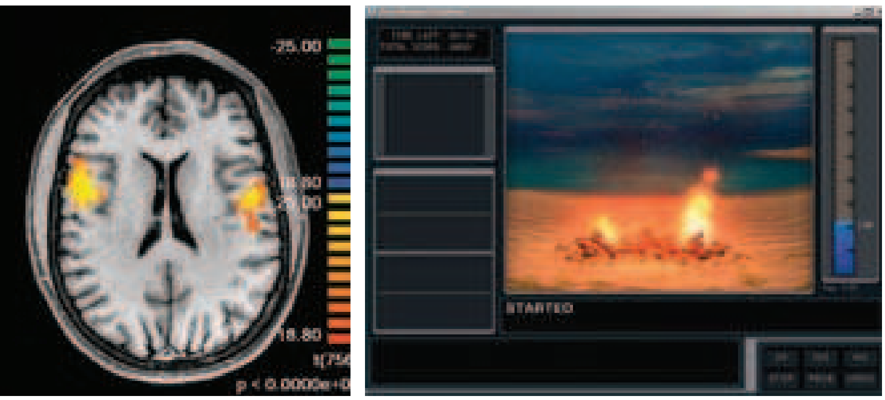
"There are potentially dozens of diseases of the brain and nervous system caused by an inappropriate level of brain activation in different areas," says deCharms. He cautions that fMRI feedback is not yet ready for clinical use—he and Mackey are still confirming their results in long-term clinical trials. But even as he refines the use of the technique for treating pain, deCharms is now testing it in patients with anxiety disorders. And other scientists are running or planning pilot studies of fMRI feedback to treat depression, stroke, attention deficit hyperactivity disorder (ADHD), and post-traumatic stress disorder.

Mind Control

DeCharms was still a graduate student at the University of California, San Francisco, in the 1990s when he started studying how the neural connections in the brain grow and change with experience, a phenomenon called neuroplasticity. Neuroscientists knew that repeatedly exercising parts of the brain can elicit permanent changes in the complex neural circuitry responsible for, say, hearing or vision. DeCharms theorized that by consciously increasing or decreasing the neural activity in specific brain areas involved

in disease, patients could control some of their symptoms and perhaps permanently change their brains for the better. DeCharms believes that patients with depression, for example, might be able to use fMRI feedback to learn to control the neurons that release the signaling molecule serotonin, and perhaps the cells serotonin acts on, as well. This would achieve the same goal as drugs like Prozac—increasing the amount of serotonin available in the brain—but might not produce side effects.

"If you practice a new form of dance, the first thing that happens is you learn to do the activity better. You engage the musculature, and it becomes stronger," says deCharms. "Eventually, your physical body has been changed. It's a long-lasting effect, even when you're not consciously trying." One key to strengthening the right dance muscles, of course, is feedback on your performance: dance studios always have mirrors on the walls. DeCharms hoped the same process would work in the brain, if he could find a way to measure brain activity rapidly and accurately enough for patients to learn to control it and to mimic desired patterns.



During one fMRI session, I was able to control activity in my right and left insula (pictured left), which is represented by a computer graphic of fires on the right and left sides of a beach (right).

COURTESY OF OMNEURON

The idea of using feedback in the brain is not new. For 30 years, scientists have used electroencephalograms (EEG)—a technology that measures electrical activity coming from the brain—to train people to elicit or maintain a particular type of electrical pattern. Results from preliminary studies suggest that such training is somewhat effective for treating ADHD and substance abuse, though large, placebo-controlled studies have not yet been completed. But because EEG technology picks up electrical activity spanning multiple brain areas, its usefulness for specific feedback is limited. DeCharms wanted to target the anatomically tiny brain structures involved in disease, and in sensations like pain.

In contrast to EEG, fMRI measures the blood flow in precise areas of the brain, yielding much finer spatial resolution. It shows which areas are working hardest during a specific task, and it can also point out which parts of the brain are functioning abnormally in specific diseases. But for deCharms, it was the development of real-time fMRI that was the breakthrough. FMRI generates an enormous amount of data, which used to take days or weeks to analyze and interpret. But newer algorithms and greater computing power have collapsed that processing time down to milliseconds. That means scientists—and subjects—can watch brain activity as it happens.

For deCharms and his collaborators, this type of fMRI held a powerful appeal. They theorized that people with neurological or psychological disorders could perform mental exercises to try to modulate activity in specific neural systems that had gone awry and get immediate feedback on which strategies were most effective. Then they could use those strategies to feel better.

Tigers and Pain

I've suffered from chronic back pain for five years, the symptoms persisting despite an array of treatments: stomach-wrenching amounts of ibuprofen, prescription painkillers that made me woozy, lengthy ergonomics consultations, and months of physical therapy and acupuncture. My problem is not uncommon. An estimated 50 million Americans suffer from chronic pain, and for a large percentage of those patients, existing therapies are inadequate.

Pain is a complex phenomenon. It depends both on neural signals that are generated during tissue damage, as when you grab a hot pan, and on a higher-level system that interprets those signals to form the pain experience—an interpretation that may be altered by your emotions and level of attention. For example, soldiers wounded on the battlefield often don't feel the extent of their injuries until they are out of danger. So while pain is an adaptation that evolved to help us avoid bodily injury, our brains have also evolved a sophisticated system for turning it off. "You need to be able to run from a tiger, even if you're hurt," says deCharms.

DeCharms chose pain as his first test of real-time fMRI technology, partly because the need is so great and partly because the neurological circuit that underlies pain is well understood. Opioid drugs, such as morphine, target these neurons chemically. Implantable stimulators, which can be an effective treatment for pain, target the circuit with small jolts of electricity. DeCharms, on the other hand, wanted to try to target the system consciously, through cognitive processes.

In last December's paper in the National Academy journal, deCharms, Mackey, and their collaborators described a study in which participants learned a series of mental exercises derived from strategies used in pain clinics. For example, they might have been asked to imagine the sensa-

tion of their brains' releasing painkilling compounds into the aching area, or to imagine that their painful tissue was as healthy as a pain-free part of their body. Subjects then climbed into the MRI scanner, where they wore special virtual-reality goggles that displayed the activity in a part of the brain involved in feeling pain—the anterior cingulate cortex. They were instructed to try to increase or decrease the activity by performing the exercises. The MRI data gave them direct feedback on how well their mental strategies were working, allowing them to adjust their technique. Some people picked up the knack quickly, while others needed several sessions to learn appropriate control methods.

Eight patients with chronic pain that wasn't adequately controlled by more conventional means reported a 44 to 64 percent decrease in pain after the training, three times the pain reduction reported by a control group. Those who exercised the greatest control over brain activity showed the greatest benefit.

The researchers also designed an elaborate set of controls to show that the results didn't simply reflect the placebo effect or an artifact of the experimental process. For example, subjects who did not get fMRI feedback but were instructed to focus attention to and away from their pain did not show as much pain relief. Patients who got fMRI feedback from another part of the brain also did not benefit; nor did patients who got feedback from the cingulate of another person. "If expectation or being in the scanner were contributing ... then that group should have seen a similar result," says deCharms. The researchers also conducted tests in which chronic-pain patients were given more-traditional biofeedback data, such as heart rate or blood pressure. Patients who received fMRI feedback had a significantly greater reduction in pain.

However, some scientists say it's still not clear what kind of role attention, or even emotion, is playing. "In our experience, people are so engaged in the task, they don't even know how long they're in the [MRI]," says Seung-Schik Yoo, a Harvard University neuroscientist who is also studying real-time fMRI. "If someone is so captivated, they could forget to pay attention to the pain." And success in controlling the activity levels shown on the screens could further distract a patient from the pain. "When it works, time flies," says Yoo. "When it doesn't, you get frustrated." He adds that the best way to determine whether test subjects are permanently affecting their brains will be a long-term clinical trial, like the one deCharms and Mackey have under way. Still, says Yoo, "Their work has paved the way in pain control using this new technique."

All in Your Head

When I told my father about my trip to Omneuron, he asked a question that deCharms is asked often. If you can mentally control pain, why do you need MRI feedback? Shouldn't the pain, or lack of it, be feedback enough?

The short answer is no. "No other technique that involves feedback has been able to do this sort of thing that well," says Peter A. Bandettini, director of the fMRI core facility at the National Institutes of Health in Bethesda, MD. According to Bandettini, figuring out why the fMRI feedback is effective is one of the big remaining tasks. He says the answer lies partly in the way fMRI pinpoints precise areas of the brain. But that still leaves a huge question: how do patients actually manipulate the activity in those areas? How do they will control over activity levels? "People figure out how to change the activation, but they don't know exactly what they do," he says. "I think if we learn more about that, the technique will become more widely applicable."

Mackey hopes to eventually unravel the neural systems responsible for the painkilling effects. It's possible that activating the cingulate leads to the release of chemicals such as endorphins, natural painkillers produced by the brain. In fact, the process may be similar to the one that causes the placebo effect. Placebo treatments can have a profound effect on pain and on certain diseases, notably depression—even inducing changes in the brain. Recent studies show that sham painkillers can trigger the release of endorphins and activate the anterior cingulate, the same brain area under scrutiny in the feedback study. According to deCharms, fMRI feedback may provide a way to consciously control this process.

Even if they are uncertain about the mechanisms behind fMRI feedback, biomedical researchers are excited about exploring its possibilities. "The results from deCharms's experiment are compelling enough that people will probably be jumping in," says Bandettini. Adds Tor Wager, a psychologist at Columbia University, "The field of neurofeedback is wide open. ... We need more research that explores what people can do themselves." The possibilities are likely to grow as neuroscientists zero in on the brain areas responsible for different functions and the specific abnormalities linked to different disorders.

Many experts caution, though, that it's still too early to determine the broad therapeutic potential. "We're going to have to do the studies and see if feedback is helpful," says John Gabrieli, an MIT neuroscientist who collaborated with deCharms and is now planning to test fMRI feedback for ADHD. "We need to figure out which disorders are amenable, how long the effects last, and what contexts are needed to support them." And as in any test of a novel technology, the findings must be repeated in other labs.

It's possible that some parts of the brain are more susceptible to conscious control than others, and such differences could limit the number of areas that are responsive to fMRI feedback. The anterior cingulate cortex, for example, may be easier to control because it is involved in attention, which we actively modulate throughout the

day, as we work or daydream, read or watch television. Diseases such as depression or social phobias, which can often be treated effectively with behavioral therapy, might also be good candidates for fMRI feedback, says Gabrieli.

Yoo, meanwhile, hopes to show that fMRI feedback could speed rehabilitation from stroke or other brain injuries. Patients often lose a particular function, such as speech or part of their vision, when such an injury kills a cluster of neurons. Sometimes the brain can heal itself, either spontaneously or through practice, by reorganizing nearby neurons to take over. This process generally takes place unconsciously, but Yoo says fMRI feedback could teach patients how to consciously activate the regenerating areas.

Among the most compelling therapeutic possibilities is a combination of fMRI feedback with cognitive behavioral therapy, a popular form of talk therapy in which patients learn to change negative thought patterns. During a standard session, a patient might tell the therapist about an event that provokes anxiety and then use specific mental exercises to calm down. In the version deCharms and colleagues are testing, a patient lies in the scanner and communicates with a therapist in the next room through a speaker. Both therapist and patient can watch the patient's brain activity throughout the session. Using that information, patients might try to consciously alter the activity patterns that flare up when they become anxious.

A Painful Lesson

Before I hit the scanner at deCharms's lab, we practice a few of the mental exercises that he routinely teaches his subjects. I imagine my brain releasing endorphins, their painkilling signals traveling down the length of my spinal cord to reach my lower back. To try to increase my pain, I imagine that my lower back is burning. (Trying to worsen the pain sounds counterproductive, but deCharms theorizes that learning to modulate pain in both directions will give patients more power over brain activity.) I'm shocked by how sharply I can make the pain flare up.

Now that I'm inside the scanner, the screen instructs me to try to increase or decrease the size of the fires representing my brain activity. I set to work, trying to focus simultaneously on my pain and on the screen overhead. The fires wax and wane a bit, sometimes smoldering, sometimes burning at a steady pace. My pain that day is mild, and it's difficult to tell if the fires are flickering randomly or at my will. Try as I might to extinguish the flame or coax it to a roaring blaze, the fire mostly burns low.

After about 15 minutes, the technician's voice crackles over a speaker in the scanner—my first session is over, and to my surprise, I did achieve some control. She projects onto the screen a rough graph comparing activity in the cingulate during the intervals when I tried to increase the fires with the activity when I tried to decrease them. There is a clear difference between the lines.

When the technician asks if I want to try another session, I agree, determined to do even better this time around. During this session, I switch mental strategies, which deCharms recommends as a way to find the technique that works best. Instead of imagining endorphins being released in my brain, I focus on the healthy tissue of my hand and try to imagine that my back feels just as pain-free. The fires on the screen flicker and flare, and I'm convinced I have a better handle on my neural activity. When I receive my official results several weeks later, I discover I was right. I performed best during my last session, successfully controlling the activity in my right and left insula.

Sometimes the brain can heal itself by reorganizing nearby neurons to take over for injured ones. This process generally takes place unconsciously, but Seung-Schik Yoo says fMRI feedback could teach patients how to consciously activate the regenerating areas.

DeCharms is now trying to determine the best ways to teach fMRI feedback; if long-term studies confirm his team's initial findings, and the U.S. Food and Drug Administration approves the treatment, he eventually hopes to open treatment clinics. Like a complex dance, the technique is hard to pick up, and some people are naturally better at it than others. "We need to figure out who is good at this and how to make it easier," says deCharms. His team is developing new ways to display brain activity to make feedback more effective. The fire graphic used in my session, for example, is a relatively new addition. The researchers are also doing extensive psychological screening to see if people who easily learn to control their brain activity have identifying characteristics. One of the biggest factors will probably be motivation. Feedback somewhat resembles exercise, albeit an odd mental form of it—so it requires willingness and effort.

My own test run is just a single afternoon, and I can't tell if my pain is any better. But I did seem to control select parts of my brain. And for better or worse, after two hours in the scanner, I am definitely conscious of my lower back. TR

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Homo Conexus

A veteran technology commentator attempts to live entirely on the new Web for two weeks.

By James Fallows Illustration by Istvan Banyai

Sooner or later, we all face the Dodgeball truth. This comes at the moment when you realize that one of life's possibilities—a product, an adventure, an offer, an idea—is really meant for people younger than you.

This bitter revelation is named for the relatively new Web-based service Dodgeball.com. This is a social-networking site, and it represents most of what is supposed to be advanced and exciting about the current wave of "Web 2.0" offerings. Dodgeball's goal is to help you figure out, at any moment of the day or night, whether your friends or people who might be friendly are nearby. Toward this end, users construct networks of contacts—you list your friends, they list theirs, and on it goes—and lists of "crushes," people they'd like to get to know. Then, with your cell phone or PDA, you send Dodgeball a text message saying that you've arrived at a particular bar or Starbucks or museum. Dodgeball messages you back with a list of people in your network who are within brief walking distance of your location—and tells them, and your crushes, where you are.

Dodgeball clearly meets most of the standards Tim O'Reilly, of O'Reilly Media, laid out last fall in his manifesto "What Is Web 2.0." (The paper can be found at tinyurl.com/cr5p9.) It relies on users to create and continually refine its content. It combines, or "mashes up," different kinds of data and services: mapping systems, networking software, messaging services. (The single most annoying aspect of the annoyingly named Web 2.0 movement is the use of the term "mashing up" to denote what in English we call "combining.") Dodgeball is light, mobile, interactive. And for the life of me, I can't imagine when I would use it.

Well, I *can*. Two years from now, if I'm at the Republican or Democratic national convention, I might want to find the 100 people I know amid the 50,000 I don't. Otherwise, I don't need Dodgeball to find the people who matter to me. My wife is in the other room, my kids are with their cell phones, I can trawl for friends and relatives via BlackBerry. Dodgeball is meant for people in their 20s—my children's age. Anyone my age who has signed up is probably also lurking on MySpace.

How did I come across Dodgeball? Trying it out was part of a larger journalistic experiment in living a Web 2.0–only life. For a couple of weeks this spring, I shifted as many of my activities as possible onto the Web, using new, hip technologies. Some of these shifts were merely the intensification of practices already familiar to many people—for instance, skipping newspapers and getting news only from RSS feeds and customized news sites. I listened to radio shows by podcast. I got my "authoritative" information from Wikipedia and all traffic and travel info from Windows Live Local and Google Earth.

I went further. I shopped for everything except food on eBay. When working with foreign-language documents, I used translations from Babel Fish. (This worked only so well. After a Babel Fish round-trip through Italian, the preceding sentence reads, "That one has only worked therefore well.") Why use up space storing files on my own hard drive when, thanks to certain free utilities, I can store them on Gmail's servers? I saved, sorted, and browsed photos I uploaded to Flickr. I used Skype for my phone calls, decided on books using Amazon's recommendations rather than "expert" reviews, killed time with videos at YouTube, and listened to music through customizable sites like Pandora and Musicmatch. I kept my schedule on Google Calendar, my to-do list on Voo2do, and my outlines on iOutliner. I voyeured my neighborhood's home values via Zillow. I even used an online service for each stage of the production of this article, culminating in my typing *right now* in Writely rather than Word. (Being only so confident that Writely wouldn't somehow lose my work—or as Babel Fish might put it, "only confident therefore"—I backed it up into Gmail files. And being equally only confident therefore in Gmail, I cheated and made lifesaver backups on my own computer in Word.) And this is only an abbreviated list of what I did on the new Web.

There was one obvious conclusion to draw from this experience, and it's the opposite of the Dodgeball revelation. A lot of these sites and services are terrific for people of any vintage, and they can handle more of one's daily chores than I would ever have imagined. Their "social" aspect is valuable in small but real ways. After my wife and I made each other authorized viewers of our respective Google calendars, we didn't have to bicker about whether we had already made dinner plans for three weeks from Tuesday.

Web 2.0's most important step forward seems to be the widespread adoption of Ajax–a combination of XML and other technologies that can make a plain old Web page nearly as responsive to commands as a "real" application like Excel or Outlook. The beta version of Yahoo's new mail utility is one illustration: it can move, delete, and offer previews of incoming messages just about as fast as my normal Outlook can. Writely is even more impressive. In all the usual tools and tricks of word processing–editing, deleting, changing formats, cutting and pasting–Writely's speed, over a broadband connection, is hard to distinguish from a desktop version of Word's; but unlike Word, Writely is truly of the Web. I could (had I wished) have shared documents and collaborated with fellow writers or edited my documents from any location.

Here is what you would know if you'd spent the spring the way I did:

The new Web is analog, not digital. By which I mean it is not the result of a single, big, discrete innovation. Rather, it represents a continuum of new ideas, from the slightly evolutionary to the dramatically different.

Consider the true darlings of Web 2.0, and the wide variation in the technologies and insights crucial to their success. Google Earth is entrancing because it combines extremely detailed worldwide imagery, technology that lets users "fly" from place to place, and a programming interface that lets users attach new data to images that they can share with other users. Google itself succeeded technically because of its PageRank algorithm for evaluating Web pages, but what made it so financially powerful were the AdSense and AdWords advertising networks. Skype emerged because its inventors were looking for a (legal) way to use the peer-to-peer technology that had gotten them into trouble as the basis for Kazaa, a file-sharing network. EBay understood the importance of "trust" rankings to allow sellers to buy from unknown vendors, but what made *it* king was the old-fashioned logic of monopoly, which means that once a certain auction site becomes popular, both buyers and sellers have an incentive to use only that site. Flickr, with its easy-upload systems and vast storage space, managed to keep pace with seven-megapixel digital photos and the proliferation of camera phones. MySpace and Facebook applied social-networking technology to the eternal interests of young people on the prowl.

These Web 2.0 companies are similar in that they're all doing good business now; but they're doing it for a wide variety of reasons and with wildly different histories and technical strengths. Their success is a welcome change from the Web 1.0 connotations of bubble, crash, and dashed hopes. But they don't constitute as distinct a movement.

We don't actually live in an online world. If, like me, you are constantly irradiated by Wi-Fi signals and have your BlackBerry always within reach, even at night, you may have begun to suspect that you are, if anything, connected all too much of the time. But that suspicion evaporates the moment you actually *need* information that resides somewhere, far away, on a server.

Google Calendar is great, but you can't consult or change it while you're sitting on a plane. The same is obviously true of online mapping, financial, social, and entertainment programs. For all its virtues, Writely is of no use at all if you happen to be having connection problems. This is going to sound like a convenient embellishment, but the records of my service provider, RCN, will prove that it's true: for the last two hours, I have had a complete connection failure, so I've had to reconstruct this article from my "real" hard-disk files. (I am back with Writely now.) If you have any kind of life whatsoever, for several hours per day you will not be sitting at a desktop or laptop computer with a broadband connection. At those moments, Web 2.0 is for all practical purposes Web 0.0. Which brings us to…

Evolution still has a way to go. A crucial part of *Homo conexus* remains gravely underdeveloped—and as long as that's the case, all these systems will fall short of their potential. The missing adaptation is a way to get information from the Internet when you *have a signal but don't have a keyboard*. This is the dreaded realm of the handheld device.

Anyone who has watched *24* knows how PDAs ought to work. On the show, Jack Bauer is constantly having elaborate data sent to his PDA. The two huge limitations of real-world PDAs—that their screens are small and bad and their keyboards even smaller and worse—don't trouble him at all. Today's mobile handheld systems are very well adapted for voice communication and are usable enough for text messages and e-mail. But when you have to go to the real Web for information or services, as you must for many Web 2.0 applications, it's usually not worth the effort.

Most is not all: or, the virtues of the short tail. Many Web 2.0 ventures are based on the familiar principle of the "long tail," popularized by *Wired*'s editor in chief, Chris Anderson: that is, the idea that an accumulation of tiny, particular niche audiences can amount to a very large collective market. This is especially true for retailers (Amazon, eBay), portals (the updated Yahoo), and social networks (MySpace), and it explains the success of targeted advertising (Craigslist, Google AdSense). But those aspiring to use Ajax to displace desktop applications and services often employ an intriguingly "short tail" approach.

For years, software makers, notably Microsoft, have struggled with the bloatware dilemma. A small fraction of their users want specialized, elaborate new functions; moreover, the software makers themselves need to keep adding features to justify upgrades. But the more niche features they add, the more complex, buggy, and expensive their programs become, and the more off-putting they can seem to most users.

The likes of Voo2do, iOutliner, Google Calendar, and the new Google Spreadsheets have solved this problem by ignoring it. They do most things that most users of their desktop counterparts want—but almost nothing that the specialized user might. Writely lets me make bullet-point lists and choose from several fonts—but I can't add footnotes or easily change the column layout. Google Spreadsheets lets me enter formulas and values as easily as Excel does, but it cannot produce graphs or charts. And the online to-do list systems lack some of the more sophisticated features I like in BrainStorm and Zoot.

The result of this short-tailism might be a curious new "long-tail" division between online and desktop applications:

the free online apps will be for ordinary users under routine circumstances, while for-pay desktop apps may become even more bloated and specialized for high-end users. And to return to the original Dodgeball principle, there will be applications suited to users in each stage of life.

The new Web is digital, not analog. (See point number one; discuss.) By this I mean that the collective intelligence Web 2.0 supposedly marshals is most impressive when it sends big, distinct, yes-or-no signals, and worst when it attempts to offer more nuanced judgments.

For instance, eBay could not have gotten a foothold without its rating system, which establishes a track record for each buyer and seller. The system suffers from ridiculous grade inflation: "#1 AAAA++++ EBayer! Best ever!!!" doesn't mean much more than "This person shipped me what she promised." But if you see a string of 200 successful transactions with only two complaints, you feel better about sending off money than you otherwise could. The fruit of eBay's rating system is binary information: this seller is okay, that one is not.

While such up-or-down judgments are generally useful, more refined distinctions, in my experience, are not. Pandora is a charming site that claims to have mapped the "genomes" of different kinds of music, so that if you tell it what songs you like—Chet Baker's jazz vocals from the 1950s, say—it will bring you lots of other music that you'll like, too. This is the audio version of Amazon's ever-evolving list of book recommendations, based on your past purchases. Nice ideas, in both cases. So far, none of Pandora's audio streams improves on what I'd choose for myself from its library of recordings. To be fair, I have learned about some artists I wouldn't otherwise have come across: for instance, after I told Pandora that I liked the French gypsy guitar virtuoso Biréli Lagrène, it came up with the improbably named The Frank and Joe Show. But in nearly a decade with Amazon, I've yet to experience the moment of perfect serendipity when it discovers a book I really like that I wouldn't otherwise have known about.

All this outpouring of knowledge is inspiring. If you were more churlish than I am, you would end up mocking the vast tonnage of earnest self-expression, the narcissistic self-documentation (in the form of Flickr photos), the craving for contact, the blog-based disputation, and the effort invested in metatagging that characterize the interactive Web. But I am not that churlish. I find it admirable, and deeply human.

But it is also potentially tragic. Many new Web applications are explicit about the importance of trust. You indicate your trust of certain reviewers or business partners and your mistrust of others. You build networks of contacts, and cross network barriers, based on stated trust levels. Wikipedia survives because users trust that, in general, it will be accurate, and seldom manipulated or simply wrong. Google's PageRank is one of the most important structural indicators of trust.

In fact, every bit of the Web enterprise operates on trust. Web-based commerce has gone as far as it has because of the surprisingly low level of fraud and error. Much of my financial life is now online—paychecks deposited, checks paid, 401(k) accounts fretted over, taxes filed. And increasingly, my communications are, too. The telephone barely rings these days, although I'm in better touch with more people, via Skype and e-mail, than ever before. And all this depends on the basic trust that messages will go through undistorted, unintercepted, and in general unimpeded.

In principle, we all recognize that nothing on the Internet is ever truly private. Messages sent from company e-mail accounts are in theory the company's property. Downloaded data passes through so many servers that it is no doubt stored by countless parties other than the sender and receiver. So far, for most people, this has seemed more a hypothetical problem than an urgent and unavoidable one. But if that changes, it'll mean a moment of Dodgeball truth for all of us, when we recognize that the Web 2.0 era belonged to younger, more trusting people.

In practical terms, where does this leave me? With the experiment over, I doubt that I'll use Writely again. (Yes, it does most of what I want in a word processor—but so does Word, and I can use that when I'm sitting on an airplane. Same for Google Spreadsheets versus Excel.) Maybe I'll check out YouTube when someone sends me an interesting link. I'll look at Wikipedia pages when they come up high in a search and I have a way to double-check any crucial facts. As for MySpace—nah!

But other applications have come to seem like natural parts of my daily life. Google Calendar is worth the effort—for the appointments that my wife needs to know about. I find that I leave Google Earth running all day, to check aerial views of a foreign site I've just read about or a neighborhood where I'm meeting someone for lunch. The discount travel broker Kayak has gotten my attention; eBay has retained it, for all the obvious reasons. Flickr is a good way to share photo files with my family—and keep them from jamming up my computer. I'll continue using Gmail as a backup site for important data files. As Ajax-enabled sites spread, they'll make sites that still require you to hit "refresh" or a "submit" button seem hopelessly out of date. I still don't like the label Web 2.0, I will continue to mock those who say "mash up," and I will never use Dodgeball. But I'm glad for what this experiment has forced me to see. TR

James Fallows is a national correspondent for the Atlantic.

Reviews

Books, artifacts, reports, products, objects

ANTIAGING SCIENCE

Is Defeating Aging a Dream?

A panel of independent scientists and technologists reviews criticism of Aubrey de Grey's antiaging proposals.

Last year, *Technology Review* announced a $20,000 prize for any molecular biologist who could demonstrate that biogerontologist Aubrey de Grey's "Strategies for Engineered Negligible Senescence" (SENS)—a much publicized prescription for defeating aging—was "so wrong that it was unworthy of learned debate." The purpose of the challenge was to determine whether de Grey's proposals were science or fantasy.

STRATEGIES FOR ENGINEERED NEGLIGIBLE SENESCENCE (SENS)
By Aubrey de Grey
www.sens.org

The judges of the "SENS Challenge" were Rodney Brooks, the director of MIT's Computer Science and Artificial Intelligence Laboratory and the chief technology officer of iRobot; Anita Goel, the founder and chief executive of Nanobiosym; Vikram Kumar, the cofounder and chief executive of Dimagi and a pathologist at Brigham and Women's Hospital in Boston; Nathan Myhrvold, the cofounder and chief executive of Intellectual Ventures and the former chief technology officer of Microsoft; and J. Craig Venter, the founder and president of the Venter Institute, whose computational methods hastened the completion of the Human Genome Project.

We received five submissions, of which only three met the terms of the challenge. De Grey wrote a rebuttal to each qualifying submission, and the challengers wrote responses to those rebuttals. The judges considered all these documents.

In the end, the judges felt that *no* submission met the criterion of the challenge and disproved SENS, although they unanimously agreed that one submission, by Preston W. Estep and his colleagues, was the most eloquent. The judges also noted, however, that de Grey had not convincingly defended SENS and that many of his ideas seemed somewhat fanciful.

Nathan Myhrvold, writing for all the judges, offered this summary of their deliberations:

"At issue is the conflict between the scientific process and the ambiguous status of ideas that have not yet been subjected to that process.

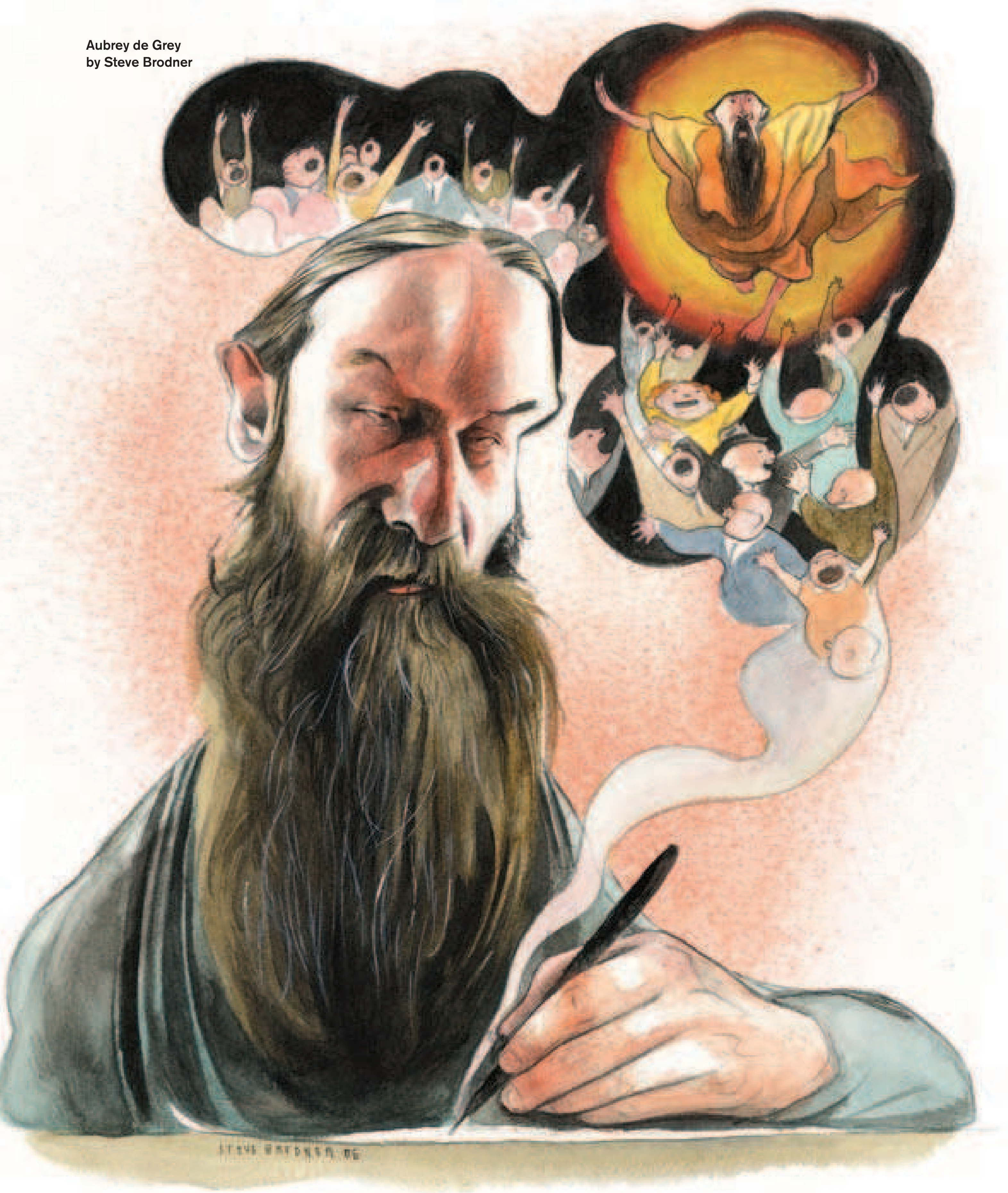
"The scientific process requires evidence through independent experimentation or observation in order to accord credibility to a hypothesis. SENS is a collection of hypotheses that have mostly not been subjected to that process and thus cannot rise to the level of being scientifically verified. However, by the same token, the ideas of SENS have not been conclusively disproved. SENS exists in a middle ground of yet-to-be-tested ideas that some people may find intriguing but which others are free to doubt.

"Some scientists react very negatively toward those who seek to claim the mantle of scientific authority for ideas that have not yet been proved. Estep et al. seem to have this philosophy. They raise many reasons to doubt SENS. Their submission does the best job in that regard. But at the same time, they are too quick to engage in name-calling, labeling ideas as 'pseudoscientific' or 'unscientific' that they cannot really demonstrate are so.

"We need to remember that *all* hypotheses go through a stage where one or a small number of investigators believe something and others raise doubts. The conventional wisdom is usually correct. But while most radical ideas are in fact wrong, it is a hallmark of the scientific process that it is fair about considering new propositions; every now and then, radical ideas turn out to be true. Indeed, these exceptions are often the most momentous discoveries in science.

"SENS has many unsupported claims and is certainly *not* scientifically proven. I personally would be surprised if de Grey is correct in the majority of his claims. However, I don't think Estep et al. have proved that SENS is false; that would require more research. In some cases, SENS makes claims that run parallel to existing research (while being more sensational). Future investigation into those areas will almost certainly illuminate the controversy. Until that time, people like Estep et al. are free to doubt SENS. I share many of those doubts, but it would be overstating the case

Aubrey de Grey
by Steve Brodner



to assert that Estep et al. have proved their point."

A majority of the judges also argued that if SENS was not exactly science, de Grey (a computer scientist by training) had described his proposals as a kind of engineering project—and they upbraided Estep et al. for not considering them on those terms. Rodney Brooks wrote, "I have no confidence that they understand engineering, and some of their criticisms are poor criticisms of a legitimate engineering process."

Craig Venter most succinctly expressed the prevailing opinion. He wrote, "Estep et al. in my view have not demonstrated that SENS is unworthy of discussion, but the proponents of SENS have not made a compelling case for it."

In short, SENS is highly speculative. Many of its proposals have not been reproduced, nor could they be reproduced with today's scientific knowledge and technology. Echoing Myhrvold, we might charitably say that de Grey's proposals exist in a kind of antechamber of science, where they wait (possibly in vain) for independent verification. SENS does not compel the assent of many knowledgeable scientists; but neither is it demonstrably wrong.

Therefore, the challenge remains open. In recognition of their careful scholarship, however, Estep et al. will be paid half the value of the prize. (This represents the $10,000 that *Technology Review* pledged; the Methuselah Foundation, an organization founded by de Grey to promote antiaging science, pledged the other half.)

Below are short abstractions from Estep and his colleagues' submission, de Grey's rebuttal, and the challengers' counterresponse. The full versions of all three submissions to the SENS Challenge, with full citations and footnotes, can be found at www.technologyreview.com/sens/. —*Jason Pontin*

Life-Extension Pseudoscience and the SENS Plan

By Preston W. Estep III, Matt Kaeberlein, Pankaj Kapahi, Brian K. Kennedy, Gordon J. Lithgow, George M. Martin, Simon Melov, R. Wilson Powers III, and Heidi A. Tissenbaum

Recent scientific advances have taken gerontological research to exciting new frontiers, giving many scientists increased confidence that human aging is to some degree controllable *(see "A Clue to Living Longer," p. 94)*. We have been on the front lines of some of these developments, and we are proud to be part of the increasingly productive biomedical effort to reduce the pathologies of aging and age-associated diseases—and to extend healthy human life span to the greatest degree possible.

"SENS bears only a superficial resemblance to science or engineering. … de Grey's writings in support of it are riddled with jargon-filled misunderstandings and misrepresentations. …[It] is pseudoscience."

In contrast to those who have engaged in clearly justifiable speculation regarding future advances in human longevity, a few people have made claims that biological immortality is within reach. One, Aubrey de Grey, says he has developed a "detailed plan to cure human aging" called "Strategies for Engineered Negligible Senescence" (SENS). This is an extraordinary claim, and we believe that extraordinary claims require extraordinary evidentiary support.

In supplementary material posted on the *Technology Review* website, we evaluate SENS in detail. Briefly, here are our conclusions: first, SENS is based on the scientifically unsupported speculations of Aubrey de Grey, which are camouflaged by the legitimate science of others; second, SENS bears only a superficial resemblance to science or engineering; third, SENS and de Grey's writings in support of it are riddled with jargon-filled misunderstandings and misrepresentations; fourth, SENS's notoriety is due almost entirely to its emotional appeal; fifth, SENS is pseudoscience. We base these conclusions on our extensive training in the areas covered by SENS, including the engineering of biological organisms for the purpose of extending life span.

Most scientists believe that pseudoscience poses a real danger to the integrity and public image of science. Because SENS has been recognized by experts as pseudoscience but has nevertheless been featured widely and uncritically in popular media, we devote the rest of this short note and the first section of our full article on technologyreview.com to this troubling aspect of SENS.

How should the nonexpert separate the false promises of pseudoscience from the likely outcomes of rigorously applied biomedical science and engineering? The long history of pseudoscientific claims points to common identifying features of pseudoscience that are rarely or never associated with real science or engineering.

The prefix "pseudo" means "false," and pseudoscience is generally accepted to mean practices that superficially resemble science but violate central scientific precepts. Richard Feynman, a widely respected physicist and staunch defender of science, called some kinds of pseudoscience "cargo-cult science." Feynman thought the South Sea Islanders who created elaborate but superficial simulacra of airports, antennas, and other technology in an attempt to attract heavenly "cargo" offered a powerful metaphor for these efforts to imitate the trappings of science.

We agree with Feynman that cargo-cult rituals and pseudoscience alike lack a certain kind of integrity, an honesty that will not settle for convenient but

superficial explanations no matter how desperately we wish them to be true. There are other important differences between science and pseudoscience, and a primary feature of our full article on technologyreview.com is a list of general features of pseudoscientific plans for extension of human life span.

Given the recent successes of life-extension research and the emotional response they provoke, Aubrey de Grey will not be the last to promote a hopelessly insufficient but ably camouflaged pipe dream to the hopeful many. With this in mind, we hope our list provides a general line of demarcation separating increasingly sophisticated life-extension pretense from real science and engineering, so that we can focus honestly on the significant challenges before us.

Rebuttal of Estep et al.'s Submission

By Aubrey de Grey

Estep et al.'s challenge tactics center on repeating the word "unscientific" in the apparent hope that this will render the judges oblivious to the absence of substance in their submission. Their abstract consists entirely of claims of their own scientific infallibility, aspersions on my methods and credentials, and blurrings of the distinctions between the methods of science and those of technology. Not wishing to descend to such tactics, I will ignore their invective and instead summarize here my detailed enumeration (posted on the *Technology Review* website) of the flaws in the specific criticisms they make in their full submission.

Estep et al. state that "any claim regarding extreme extension of life span in higher organisms must be regarded with extreme skepticism, and the evidentiary and logical support for such a claim must be as extraordinary as the claim itself." This is correct for claims that such extension *has* been achieved, but not for claims that a particular plan for achieving it *might* succeed. Since human aging causes immense suffering and death, any plan that might dramatically postpone it merits detailed expert review; only if its chance of success can be evaluated as negligible should we ignore it. Similarly, their statement that "any claim of a cure for human aging ... must be pseudoscience" forgets that whereas science is about reducing our ignorance, technology is about sidestepping our ignorance.

"Their statement that 'any claim of a cure for human aging … must be pseudoscience' forgets that whereas science is about reducing our ignorance, technology is about sidestepping our ignorance."

In the full draft of their criticism, Estep et al. highlight the three most challenging of my seven categories of aging "damage" and scorn my preferred approaches to combatting them. One such approach, allotopic expression (AE), has been pursued experimentally for 20 years. Each of the others has been the focus of a full-day workshop, one of them sponsored by the National Institute on Aging; together the workshops involved eight eminent experimentalists spanning all relevant disciplines. Enthusiasm for my approaches was demonstrated by the fact that 14 of 16 attendees signed the articles arising from their workshops as coauthors, and the others declined for reasons unrelated to their evaluation of the scientific merits. Faced with this evidence that my proposals are wholly legitimate—evidence rather stronger than the experts' mere attendance at the conferences—Estep et al. simply omit it from their critique. A section of one of these articles, which they deride as "pseudoscientific pretense," was contributed by Professor Bruce Rittmann—

who, as his biography suggests, cannot easily be dismissed for lacking relevant experimental expertise (as Estep et al. so blithely dismiss me).

In my interactions with experimentalists, I always provide all the facts known to me that might help them reliably evaluate my proposals. By contrast, Estep et al. repeatedly omit key facts that Estep certainly knows (though his coauthors may not). For instance, they lampoon a prediction I made in 2000 concerning AE, without mentioning that I made it assuming that a report of a seminal breakthrough (which I described at the time I made the prediction) would be published imminently in *Science* (where it was then under review), stimulating efforts to perfect this approach. In fact, follow-up effort remained negligible until the report was finally published in 2005. It is thus grossly misleading to suggest that my optimism arose from underestimating how hard AE is. It is Estep et al., not I, who attempt to mislead readers by selectivity.

Response to de Grey's Rebuttal

By Preston W. Estep et al.

Nonexperts have relied on us to assess SENS and Aubrey de Grey's claims. Now, with his response, they can see for themselves that when he is under the microscope of public scrutiny, his response—like SENS itself—is a tangled mixture of fact and fantasy that cannot be believed. On *Technology Review*'s website, we detail some of the falsities of his response, but they are diversions from the important points in our critique. The most important point is this: SENS is an elaborate deception propelled to notoriety by its emotional appeal; its facade is built from the real science of others, but at its core, SENS is simply a collection of naïve hypotheses dressed up by misrepresentations of research in science and engineering. TR

RAIMUND KOCH/PHOTONICA/GETTY

STORAGE

The Terabyte Zone

A thousand gigabytes of hard-drive space is a blessing. Too bad there aren't better ways to manage that much data.

By Simson Garfinkel

A terabyte for less than a grand! Now, that's progress.

Maxtor's new OneTouch III external drive connects to a PC, Macintosh, or Linux computer and holds a trillion bytes of data (actually a bit less than a true terabyte, which is $1{,}024^4$ or 1,099,511,627,776 bytes). This device is fast and silent and can be comfortably carried in a backpack or a thick briefcase. Open up the box and you'll actually find two 500-gigabyte hard drives: the OneTouch III uses a technology called RAID (redundant array of independent disks) to combine the drives into a single high-capacity virtual device.

ONETOUCH III TURBO EDITION HARD DRIVE
Maxtor
$900 list, $700 street

I have been using external hard drives for large-scale data storage for more than a decade. Of course, the definition of "large-scale" has changed considerably over that time. I bought my first external hard drive back in 1993; it cost $995 and stored one gigabyte. In the intervening years, engineers have improved magnetic storage technology even faster than they've increased computers' processing power. In 1993, my desktop workstation ran at a clock speed of 33 megahertz and had 32 megabytes of RAM; my desktop computer today runs at 100 times that speed and has 32 times as much RAM. But the Maxtor

holds a thousand times as much data as my first external drive.

Over the years, I've bought drives from literally a dozen manufacturers. But I've never found one as good as the Maxtor OneTouch III—and not just because of its mammoth capacity, which puts it among the largest hard drives on the consumer market. The device is virtually noiseless in operation and cool to the touch, both important features in today's home offices. Unlike most other drives, the OneTouch III has three different interfaces on the back—USB 2.0, Firewire 400, and Firewire 800. That means it will work with practically every desktop and laptop on the market today; if your computer doesn't have one of these interfaces, you can buy a card for less than $30. The connector is a sturdy barrel that's unlikely to break—no delicate pins here.

All this engineering makes the OneTouch III a pleasure to use. But why would anyone actually need a terabyte of storage in a home or small office? And will someone who has it actually know what to do with it?

Back when I bought my gigabyte drive in 1993, it wasn't very hard to put all that storage to use. CD-ROMs, which were just beginning to become widespread, stored 600 megabytes each. Copying a single CD-ROM to the hard drive could nearly fill it up. It's a bit harder to generate a terabyte of data, and the average consumer doesn't need quite that much storage—yet. But in a few years, a terabyte for a household will seem pathetically small. The reason, of course, is digital video.

Music and still photography have been driving the need for consumer storage in recent years. Even with compression technologies like MP3 and JPEG, songs and high-resolution still photographs still require between one and five megabytes each. Collect your photos of the family trips, throw in a few birthday parties, and add the music collection of just one teenager, and pretty soon you need tens of gigabytes, if not a few hundred, to keep it all at hand.

But digital video is a different animal entirely. MiniDV video cameras record digital video on tape at 250 megabytes per minute, or 15 gigabytes per hour. Many new digital video cameras have flash RAM or miniature hard drives that can capture several gigabytes of compressed video per shooting. And these days, most digital cameras will create video clips—files that can quickly grow to hundreds of megabytes in length. Just a few vacation videos will stuff the hard drive that came with your PC. (The largest hard drives for off-the-shelf desktop or laptop computers these days hold only about 500 gigabytes.) So as digital recording technologies become more commonplace, consumers will face a very real dilemma: either purchase terabytes of extra storage or discard their digital memory chests. I suspect many will opt for the storage.

Although there are other ways to capture and archive digital information, none offers the permanence, reliability, and convenience of hard drives. It's certainly cheaper to keep your video on miniDV tape, which costs about $4 for each recorded hour, but it's much more convenient to have all your videos on a single drive than to have them scattered across two or three shelves. Hard drives don't degrade as fast as tapes do, and unlike tape drives, they don't need to be cleaned to maintain picture fidelity.

What's more, as download services like iTunes, YouTube, the Google Video store, and Movielink become more popular, consumers will be storing not just the songs they've purchased online but also TV shows and movies. Some computers even act as digital video recorders, copying data directly from a cable or satellite feed—which will further fuel the need for storage. Devices like the Maxtor OneTouch III will fill that need.

Combining two 500-gigabyte drives is more than just a gimmick to let Maxtor say it sells a terabyte hard drive. Having two drives is actually a blessing. It makes the system either faster or more reliable than a similarly equipped single drive could possibly be.

Unfortunately, you need to choose between speed and reliability: you can't have them both. Under the default RAID configuration, called "drive striping," the OneTouch III alternates between drives as it records data files, writing the first segment to drive one, the second to drive two, the third to drive one, and so on. Because the device has two disk controllers and two sets of cache memory, it writes data roughly twice as fast as a single drive. But drive striping is risky: if either drive fails, all the data on both drives may be lost. A second RAID configuration is called "drive mirroring." In this mode, every block of data is stored on both drives. Mirroring reduces the capacity of the OneTouch III from a terabyte to 500 gigabytes, but it dramatically improves reliability: both drives have to fail at precisely the same time for you to lose data.

RAID technology and terabyte-sized storage systems were invented in the 1980s for supercomputers and moved to the world of corporate computing in the late 1990s. In that era, considerable skill was required to assemble and manage this much storage. And unfortunately, while storage technology has gotten a lot smaller and cheaper, the tools for managing all that stored data have not gotten much simpler. All of us are going to be spending more of our time trying to manage our storage devices effectively (as the choice between drive striping and drive mirroring illustrates), but there aren't yet many easy-to-use tools for organizing a terabyte of digital video.

Of course, there's always Windows Explorer or the Macintosh Finder: you can create a directory for each year and store your videos in chronological order. You can then use the Windows search utility, or Spotlight on a Mac, to search your collection by file name.

But what I would really like is some kind of semantic video search engine that indexes video by analyzing the dialogue or the scenes, taking into account the time of year, the location, and the people in the picture. Then I could simply say, "Computer, find all video clips of my mother in a red dress." Unfortunately, that kind of search technology is still in the research stages.

The Maxtor drive does make one storage task easier: backing up other hard drives. The word "OneTouch" refers to a prominently placed push button on the front of the device; pressing that button causes your host computer to run Retrospect Express, the personal backup program included with the drive.

But I don't use Retrospect Express. When I back up my laptop, I just copy all the files into a new directory. This is less efficient, but it's a lot faster to recover the backed-up files using the Macintosh Finder or Windows Explorer than using Retrospect's "Restore" facility.

Of course, having a terabyte of backup capacity could change our notions about what it means to back up a computer in the first place. Instead of storing a snapshot of all the files on the computer at a particular point in time, the way automatic backups do, we could continuously store every version of every file that we've ever edited. Your browser's "history" could be a real history, with a copy of every Web page you ever viewed, every song or video clip you ever downloaded. Storage on this scale would mean never having to hit "delete." These kinds of desktop backup systems are also a current subject of research.

With great storage comes a great need for storage management. Today's terabyte drives deliver the bytes—but unfortunately, it's still up to the user to know what to do with them. TR

Simson Garfinkel researches computer forensics at the Harvard Center for Research on Computation and Society.

SCIENCE FICTION

Vinge's Singular Vision

Cyberfiction's founder returns with a preview of our virtual future.

By Stewart Brand

Vernor Vinge dedicates his new novel, *Rainbows End*, "To the Internet-based cognitive tools that are changing our lives—Wikipedia, Google, eBay, and the others of their kind, now and in the future." The book is an imagining of how those technologies might develop over the next two decades. But publication of *Rainbows End* is not only a literary event. The question arises, "Will Vinge influence the actual evolution of the technology?" He has done so before.

Many coders and system designers, as well as those who market their work, read science fiction for ideas as well as entertainment. A few fictional ideas gain such currency that they affect the real world. In 1984, the "cyberspace" of William Gibson's *Neuromancer* inspired a generation of early netheads as they imagined the "consensual hallucination" (to use Gibson's phrase) that became the World Wide Web. Equally, Neal Stephenson's "Metaverse," the massively shared virtual reality in his 1992 novel *Snow Crash*, helped lead to multiplayer worlds such as Second Life.

RAINBOWS END
By Vernor Vinge
Tor, 2006, $25.95

But the earliest fictional evocation of an immersive virtual world came back in 1981 with Vernor Vinge's novella "True Names," in which the secretly powerful alternate reality was called "the Other Plane." By 1995 Kevin Kelly would observe in *Wired* magazine, "Many Net veterans cite *True Names* as a seminal influence that shaped their ideas about Net policy. … It became a cult classic among hackers and presaged everything from Internet interactive games to *Neuromancer*." In 1984 and 1986, Vinge struck again. With a pair of novels later published together as *Across Realtime*, Vinge proposed that technological progress would soon accelerate to a spike of such intense change that on the other side of it, humanity would be unrecognizable. His description of that metamorphosis, which he dubbed "the Singularity," has since guided many visions of 21st-century technology.

In a departure from Vinge's recent heavy-duty space operas, the Hugo Award winners *A Fire upon the Deep* and *A Deepness in the Sky*, *Rainbows End* is short. It's a picaresque of sorts, set in the 2025 San Diego first explored in Vinge's 2002 story "Fast Times at Fairmont High." In the book, everybody's real world is draped with arrays of private and shared virtual realities, and "Search and Analysis" is the core skill taught to the young and the rejuvenated old as "the heart of the economy." It turns out that the crux of a Search and Analysis world (and of Vinge's narrative) is this: who knows what, and how, and how is their knowing displayed or cloaked?

Setting the story in the near future lets Vinge build on his own real-world career teaching math and computer science at San Diego State University, as well as consulting for commercial and government organizations and writing science fiction. The novel teases and advises all those communities.

Setting the plot in motion, ultranetworked spies discover that a project for subtle, targeted mind control is under way in a fortresslike bioscience lab on the campus of the University of California, San Diego. And so this university tale features steam tunnel adventures, an extravagantly exploited graduate student, and lifelong academic vendettas (a

COURTESY UCSD PUBLICATIONS OFFICE

The setting for Vernor Vinge's *Rainbows End* is the Geisel Library at the University of California, San Diego. Vinge taught math and computer science at San Diego State University for almost 30 years.

downside of life extension). Google's current Book Search project is both praised and satirized. Why shouldn't humanity's entire intellectual past be as indexed, organized, linked, and searchable as information that was digital from its creation? Too bad the books themselves are destroyed as they are scanned. (The real Google is more careful.)

National-security analysis, in *Rainbows End*, is conducted by free-floating swarms of analysts who can generate and sift a thousand conjectures simultaneously but can also collapse into procedural dispute. Surveillance is done competently by obsessive hobbyists. Military action consists mainly of signals intelligence.

Vinge has a high old time with the conventions of science fiction and fantasy. Of course, the fate of everything is at stake. The world is in a permanent state of dread that some evildoer might convert one of the innumerable new cyber- and bio- and cogno- and nanotools into a weapon of annihilation. Even the coolest new technologies are beset with problems. Yes, you can absorb a skill like a new language with "just-in-time training," but the process is so immersive you might get permanently stuck in it. Yes, you can live a lot longer, but different ailments are differentially susceptible to cure, and some people are more fully rejuvenated than others.

Fantasy fandom is a huge force in Vinge's world, where massively multiplayer games are the dominant entertainment medium, and the legions of enthusiasts in "belief circles" can not only project their fantasies onto the increasingly attenuated fabric of the real world but pit their fictional worlds against each other in epistemological combat. Heroic figures like Dangerous Knowledge and Librarians Militant (both from a Terry Pratchett–like fantasy domain) and the Greater Scooch-a-mout and Mind Sum (from a Pokémon-like franchise) duke it out in front of a real library and an online flash crowd of millions.

Vinge's technological speculations are among the book's chief pleasures. His professional association with the Internet, which dates to its beginning, allows him to make some interesting proposals. How about a "Secure Hardware Environment" as the deeply reliable and unhackable foundation of everything online and virtual? How about "certificate authorities" that offer people the option of accountability amid the blizzard of faux personalities lashing through cyberspace?

See Vinge rejoice in the nuances of a network decaying toward breakdown:

> The network problems were getting a *lot* worse. There were strange latencies, maybe real partitions. Blocks of the virtual audience were being run on cache. Single-hop still mostly worked, but routed communication was in trouble. Huynh stepped a few feet to the side and managed to find a good diagnostic source. There were certificate failures at the lowest levels. He had *never* seen that before. *Even the localizer mesh was failing*. Like the holes in a threadbare carpet, splotches of plain reality grew around him.

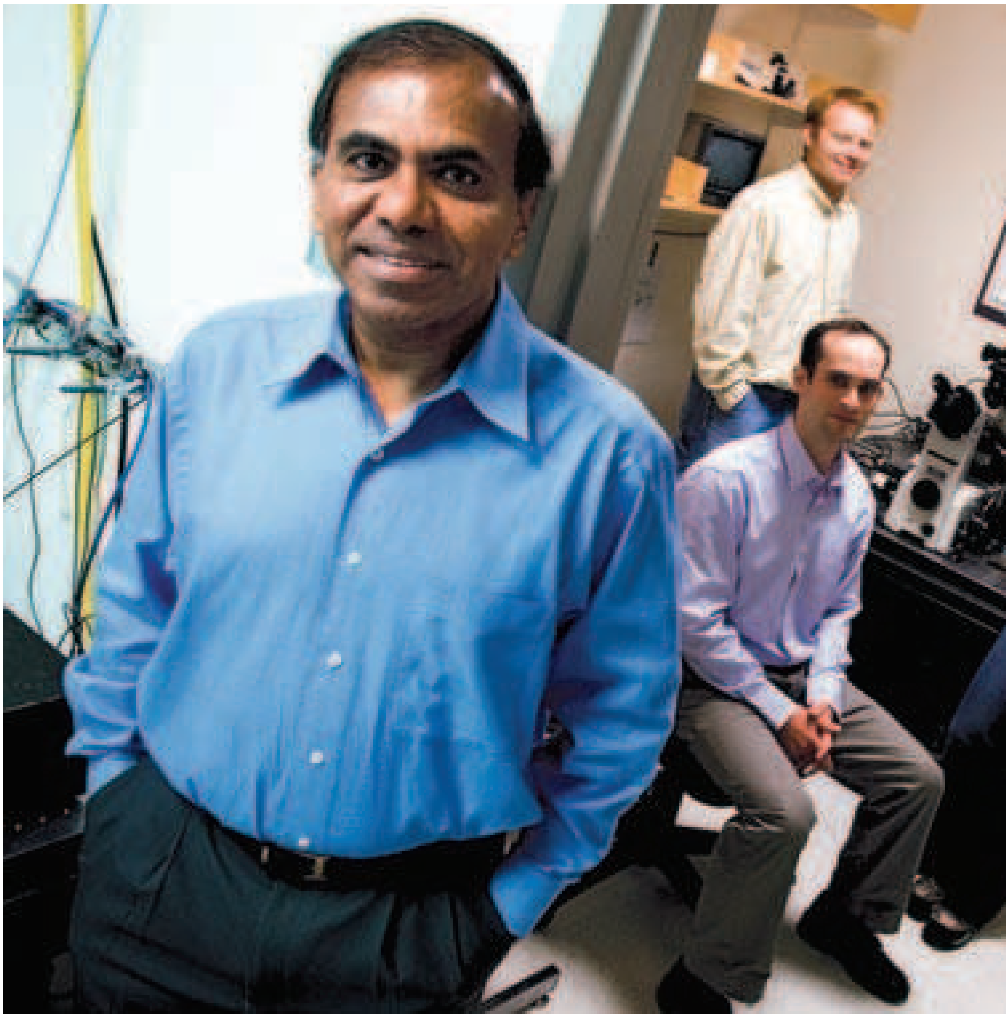
The most intriguing character in *Rainbows End* is its hidden hero, the enigmatic figure Rabbit, a faux being whose puissance is matched by his juvenile humor. Is he an artificial intelligence? If so, what does *that* portend? Happily, Vinge is planning a sequel that will explore the matter further. TR

Stewart Brand was the founder of the Whole Earth Catalog *and a cofounder of the WELL, Global Business Network, and the Long Now Foundation.*

Biology and the Engineer

Subra Suresh is borrowing tools from physics to understand nanoscale changes in diseased cells.

By Michael Fitzgerald



John Mills fiddles with the knobs on a microscope, but instead of looking into the eyepiece, he stares at a sphere displayed on a laptop's screen. The laptop is connected to a video feed coming from the microscope, and Mills watches as fluids on a slide flow past the sphere, a tiny silica bead. After a few seconds, something that looks like a dented doughnut appears on the screen. It's a red blood cell, and Mills quickly adjusts the microscope's knobs until the bead "catches" the cell. He turns the knobs again, and a second silica bead appears and attaches to the cell. Then Mills slowly maneuvers the silica beads, which are coated with proteins that stick to the blood cell, so that the cell stretches out into the shape of a cigar.

Mills, a PhD student in materials science and engineering at MIT, is demonstrating what are probably the world's most powerful optical tweezers, which he built as part of his thesis work with his advisor, Subra Suresh. Optical tweezers, which were developed in the mid-1980s, use the force of light to manipulate tiny objects. In this case, Mills uses a pair of lasers to control the silica beads. Using the beads as "handles," Mills can apply a force of up to 500 piconewtons to the red blood cell—several times that possible with previous optical tweezers—to test the elasticity of the cell's wall.

Using such ultrasensitive tools to measure the physical properties of a cell, such as its stiffness, "will let us look at things in ways we haven't done before," says Suresh, a professor in MIT's Department of Materials Science and Engineering. For example, Suresh and his team are examining the way a force applied by the tweezers affects a healthy red blood cell, and then comparing the way a cell infected with a malaria parasite responds to a similar force. Suresh hopes that knowing precisely how malaria changes the physical properties of a cell could lead to better ways to treat the disease, or even to prevent it.

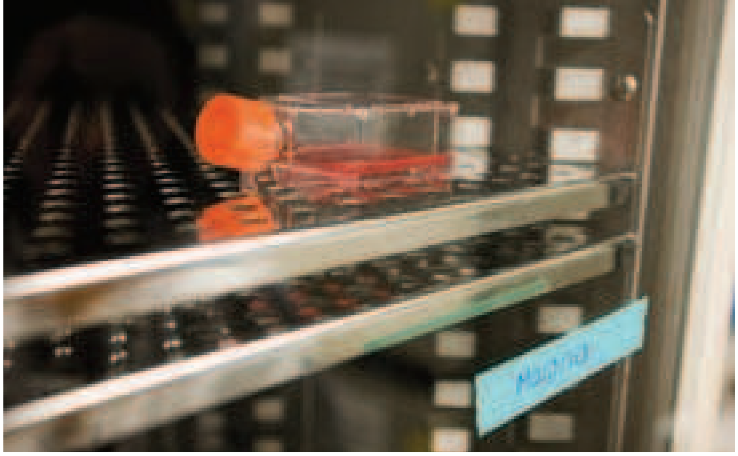
Studying such properties of biological components is relatively new ground for Suresh. As a materials scientist, he has spent much of his career studying the structural properties of materials used, say, as coatings or in thin films. While in France on sabbatical in April 2004, he spoke at a prestigious technical school in Paris, where he had a chance encounter at the cafeteria with a biology professor. The biologist did research at the Institut Pasteur and invited Suresh to speak there about his work.

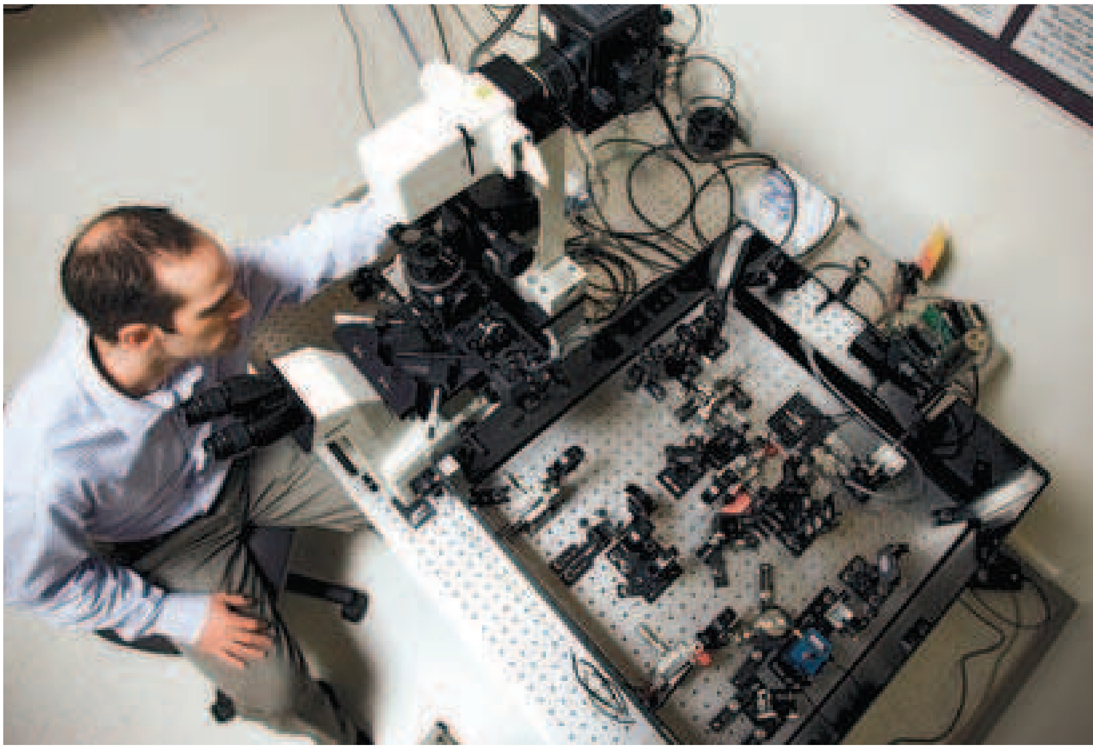
The reaction of the biologists was enthusiastic. They weren't using the precise tools—such as optical tweezers—that are relatively common in Suresh's field. And they saw that Suresh's expertise, experiments, and computer modeling might help them understand some of the physical changes that diseased cells undergo.

Losing Sleep

Although the malaria parasite, which attacks red blood cells, is one of the deadliest killers on the planet, there is a great deal scientists don't know about how it works. Scientists do know

PHOTOGRAPHS BY PORTER GIFFORD





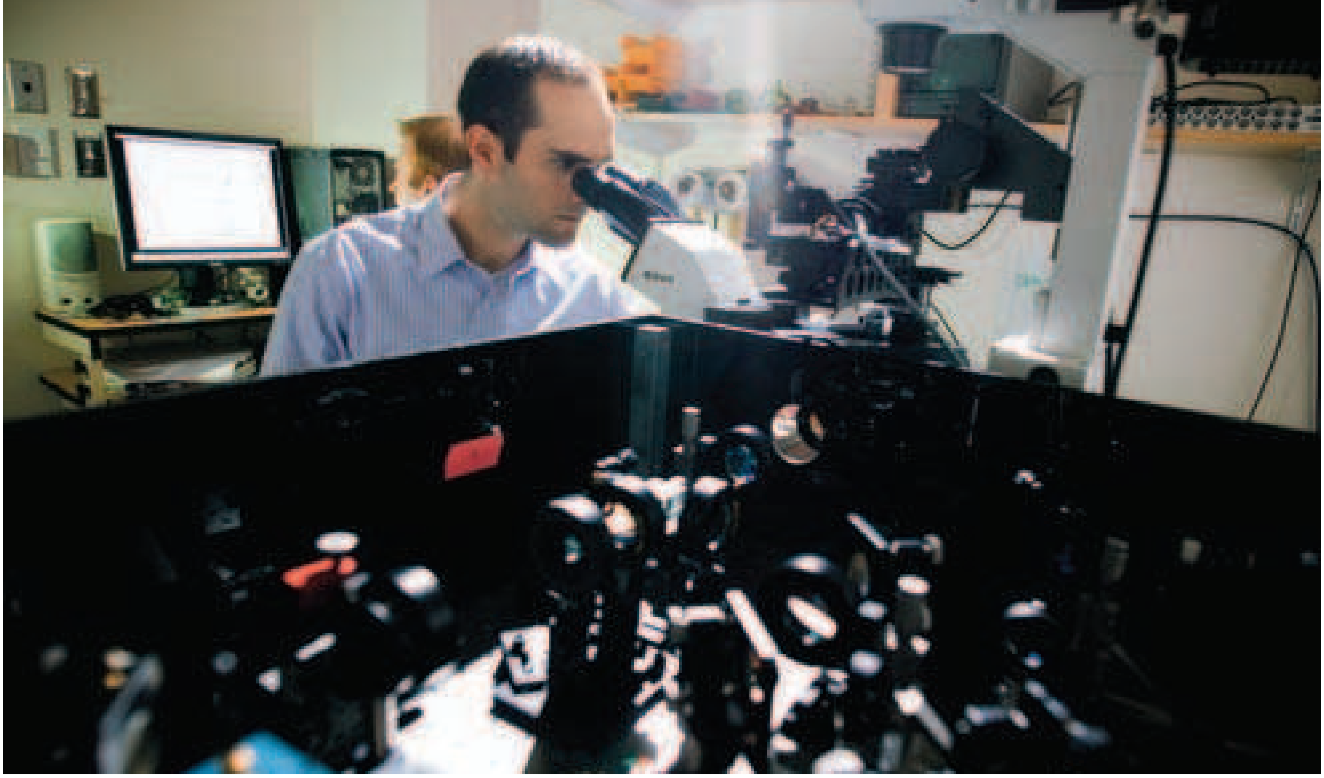
Subra Suresh and his team of researchers—David Quinn, John Mills (sitting), Monica Diez-Silva, and Ming Dao—are using optical tweezers (bottom right), a laser-based technology borrowed from physics, to study the stiffness of red blood cells infected with malaria parasites (top right). Such studies could lead to new treatments for the deadly disease.

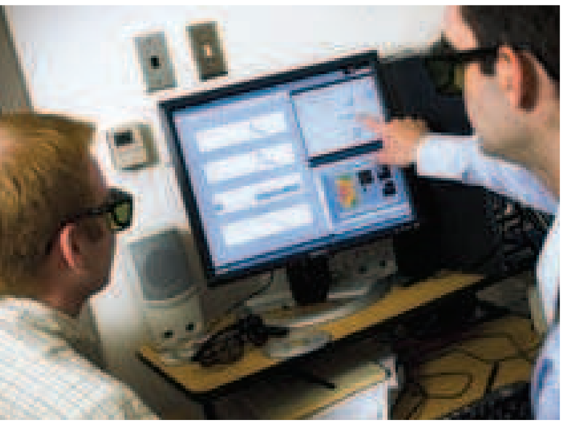
that malaria makes red blood cells stiffer, which impedes their ability to move through the bloodstream, and it makes them stickier, which causes them to clump together and stick to blood vessel walls. But Suresh's work has yielded far more precise knowledge of just how stiff red blood cells get. Researchers had believed infected cells to be about three times as stiff as healthy cells, but Suresh showed that they are in fact up to 10 times as stiff.

Malaria parasites grow to maturity within 48 hours. Suresh wants to know how the stiffness of affected red blood cells changes as the parasite matures. Experiments on such a time scale would have been almost impossible in the past: Suresh and his colleagues previously used optical tweezers that might need an hour to catch a single blood cell, and it took hours more to process the data they collected. With the new tweezers, Mills can grab a cell in seconds, and improved modeling software lets the team analyze the data in real time. The improvements in the technique make practical a series of experiments designed to study the action of specific proteins responsible for altering cells infected with malaria.

The first protein the Suresh group is studying is the RESA protein, which a malaria parasite introduces into an infected cell. The protein affects the cell membrane, and Suresh and his collaborators at the Institut Pasteur and the National University of Singapore want to see how the cell's elasticity varies at different stages of the parasite's development. The researchers hope to learn whether the protein is an attractive target for treating or preventing malaria.

In an effort to determine what role the RESA protein plays in malaria, Mills uses infected cells in which the protein is deactivated and then measures the stiffness of the cells at various points in the parasite's 48-hour growth cycle. As a control, he also measures cells in which the protein is active; the comparison should show whether the protein's inactivity at different stages





A microscope attached to the optical tweezers gives John Mills a view of how coated silica beads capture and stretch a red blood cell. The force imparted by a precisely controlled laser beam propels one of the beads (small sphere, bottom right), which attaches to a cell; affixing a bead to either end of the cell allows the researchers to stretch it out. Data are fed into a modeling program to get instant feedback (above).

of the parasite's growth has any effect on cell structure.

The 30-minute setup of the tweezers includes a series of calibrations to make sure that the force exerted by the laser is small and precise enough for experiments on the nanoscale. "My biggest complaint is that parasites don't sleep," says Mills, who has to get up at all hours to test the stiffness of cells in different stages of infection. That test involves turning on his 10-watt laser, focusing the laser on the beads, and capturing a red blood cell. He then spends about half an hour applying various degrees of force to the cell, with the data and video being fed into his computer.

Sticky Problems

Suresh points back to the computer screen, where Mills has captured another cell. But red blood cells are not solitary things. The parasite creates "knobs" on the surface of a red blood cell that make it stick to healthy cells, sometimes causing clumping in the bloodstream. Such clumping can cause tremendous internal damage and even death.

"We think we can measure the force of adhesion between two cells—a measure of the stickiness, which also plays a huge role in the development of the disease," Suresh says. "As far as we know, nobody has quantified that stickiness." Suresh hopes that determining the force of adhesion will help lead to a malaria treatment that improves blood flow.

Although Suresh is excited about the biological work he's doing, he's also circumspect. Nanoscale measurement of the physical properties of biological cells is really still in its early phases, he says. "We're just starting to put this together. It'll be five years before we can start to see where we can go. We still have to understand the science. Then we can figure out the potential for treatments." TR

From the Labs

Current research in nanotechnology, information technology, and biotechnology

NANOTECHNOLOGY

Bio-Inspired Nano Synthesis

Sponge studies lead to a method for making novel materials

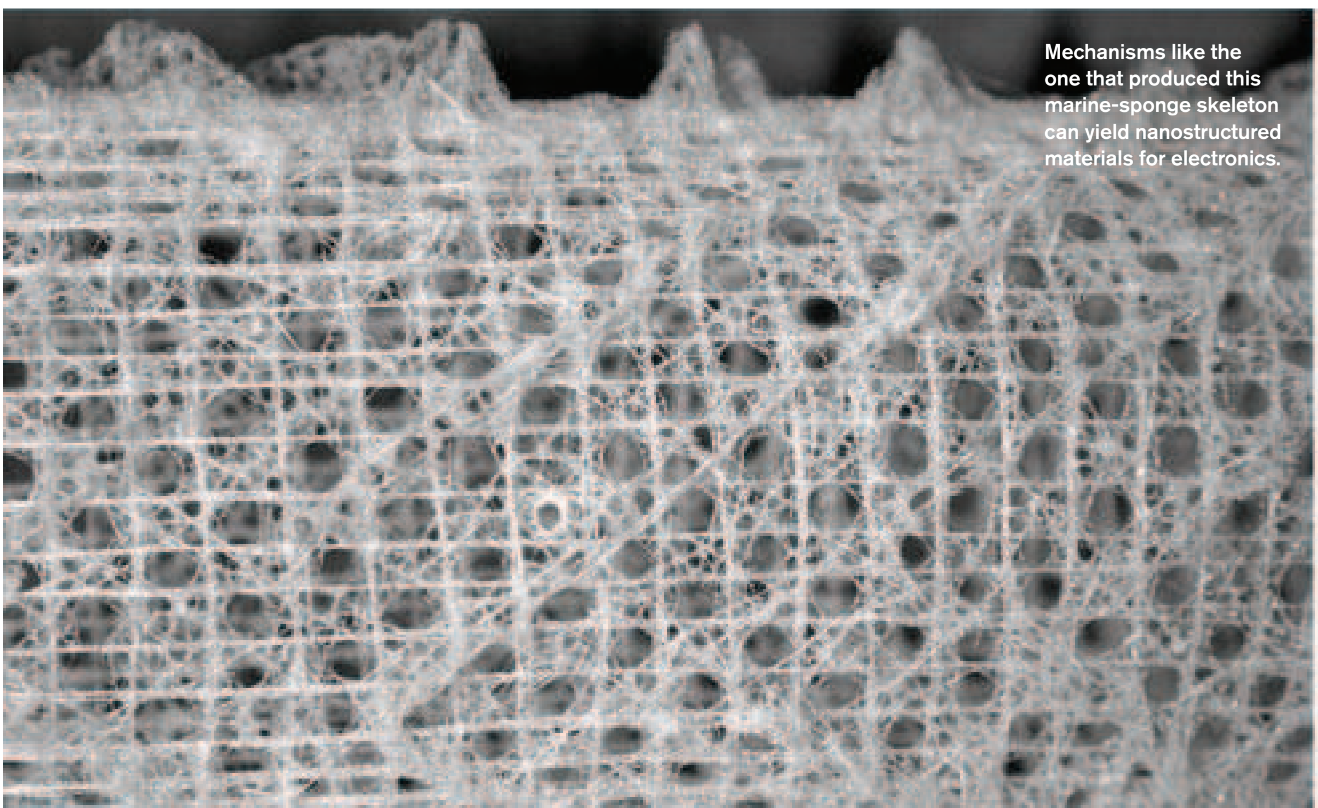
SOURCE: "Kinetically Controlled Vapor-Diffusion Synthesis of Novel Nanostructured Metal Hydroxide and Phosphate Films Using No Organic Reagents"
Birgit Schwenzer et al.
Journal of Materials Chemistry 16: 401–407

RESULTS: Using mechanisms inspired by marine sponges, researchers at the University of California, Santa Barbara, have developed a technique for making a variety of thin-film materials, including semiconductors, structured at the nanoscale. Unlike other methods, the technique can produce semiconducting thin films without the use of harsh chemicals, and it works at room temperature, whereas some techniques require temperatures of 400 to 1,500 °C. So far, the researchers have used the process to synthesize 30 types of materials, some of which have novel electronic and optical properties.

WHY IT MATTERS: The process is more environmentally sound and potentially less expensive than other techniques for manufacturing thin-film materials, which are used in a variety of electronic devices. Furthermore, it could open the way for new types of materials or allow existing materials to take on new properties. For example, the large surface area of the nanostructured films could lead to higher-power batteries and more efficient solar panels.

METHODS: The process is similar to one seen in marine sponges, which assemble their intricate glass skeletons with the help of an enzyme that doubles as a physical template. The researchers expose a solution of molecular precursors to ammonia vapor, which, as it slowly diffuses into the solution, catalyzes the assembly of the precursors into the desired material. The surface of the solution acts in some ways like the sponge's enzyme template, helping to determine the material's structure. At the surface, the vapor concentration is greatest, and the material forms a smooth, thin film. As the concentration of ammonia decreases, the material grows down, extending from the film like stalactites.

NEXT STEPS: The researchers are beginning to build and test rudimentary photovoltaic and electrical storage devices made from the new materials. To produce materials that perform as well as possible, they will also need to fine-tune the assembly method and apply it to additional compounds.



Mechanisms like the one that produced this marine-sponge skeleton can yield nanostructured materials for electronics.

COURTESY OF JAMES WEAVER AND DANIEL E. MORSE/UNIVERSITY OF CALIFORNIA, SANTA BARBARA

Carbon Nanotube Computers

IBM researchers have found a way to arrange nanotube transistors into complex circuits

SOURCE: "Field-Effect Transistors Assembled from Functionalized Carbon Nanotubes"
Christian Klinke et al.
Nano Letters 6(5): 906–910

RESULTS: Researchers at IBM have selectively arranged carbon nanotubes on a surface to make transistors, an important step toward arranging them into complex circuits. To control the placement of the nanotubes, they attached them to molecules that bind to patterns of metal-oxide lines on a surface. They then demonstrated high-performance transistors assembled through this technique.

WHY IT MATTERS: Researchers estimate that transistors based on carbon nanotubes could run many times faster than anticipated future generations of silicon-based devices but would use less power. The IBM work overcomes one of the serious obstacles to nanotube-based computers: the difficulty of deliberately arranging the molecules so that they can form complex circuits.

METHODS: To make working transistors, the researchers first laid down aluminum wires using a lithographic technique. These wires served as the gates that turned the transistors on and off. They then oxidized the aluminum, creating a thin layer of aluminum oxide that acted as an insulator. The oxidized aluminum also served as a template for the carbon nanotubes. After arranging the nanotubes by allowing them to bind to the aluminum oxide, the researchers deposited palladium leads perpendicular to the aluminum wires. These leads crossed over the nanotubes, becoming the sources and drains of high-performance transistors.

NEXT STEPS: The speed of the transistors is currently limited by the large size of the leads and their poor contact with the nanotubes. One possible solution is to replace the palladium wires with metallic nanotubes. Because current fabrication techniques produce a mix of nanotubes with different sizes and electronic properties, not all of which will work well in integrated circuits, another challenge is to find reliable and inexpensive ways to isolate a preferred type of carbon nanotube.

INFORMATION TECHNOLOGY

Multifunctional Cell-Phone Chip

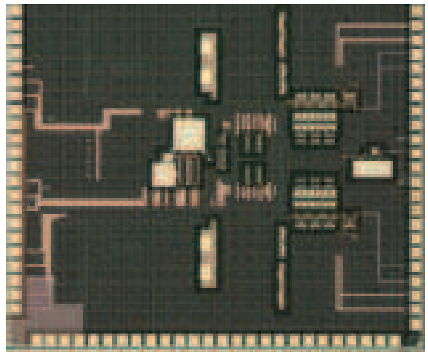
Wireless receiver can access ultrawide range of radio frequencies

SOURCE: "An 800MHz to 5GHz Software-Defined Radio Receiver in 90nm CMOS"
R. Bagheri et al.
Paper presented at the International Solid-State Circuits Conference, February 5–9, San Francisco, CA

RESULTS: At the University of California, Los Angeles, Asad Abidi and colleagues have built a low-power receiver for a wireless chip that can receive radio signals over a range from 800 megahertz to five gigahertz and tune in to the band a particular application requires.

WHY IT MATTERS: Handheld devices are offering more wireless capabilities, including Wi-Fi and GPS. For each new function, engineers need to add a chip that is tuned to a specific radio frequency. A mobile device that allows users to surf the Internet using a Wi-Fi connection requires at least two chips, one for cell-phone service and one for Wi-Fi. Abidi's wideband receiver could make it possible to tune in all frequencies with a single, universal chip. Such a chip could allow a single handheld device to access any wireless service: it could receive radio and Wi-Fi signals, provide cellular service all over the world, even open a car door.

METHODS: Abidi and his team based their research on software-defined radio (SDR), a concept first proposed in the



This prototype universal wireless chip can receive multiple frequencies.

1990s. Typically, an SDR device converts incoming analog radio signals to digital signals and then uses software to sort through the frequency bands. That requires hundreds of watts of power, however. To save power, the team modified SDR technology by using an electronic component called a wideband anti-aliasing device, previously used only in physics research. This device can access a wide range of the radio spectrum and emphasize a single band, so that only that band is converted to a digital signal. The method requires just milliwatts of power.

NEXT STEPS: The researchers have met half the challenge of building a universal cell-phone chip, but a truly universal chip would not only receive but transmit across a wide range of frequencies. Abidi's team is now working to develop components for a transmitter that operates over the same range of the spectrum as its wideband receiver.

Battery-Free Sensor

Antenna used in RFID tags powers tiny computers

SOURCE: "A Wirelessly Powered Platform for Sensing and Computation"
Josh Smith
Paper accepted for the Eighth International Conference of Ubiquitous Computing, September 17–21, Orange County, CA

RESULTS: Using the same approach that makes passive RFID tags come to

COURTESY OF ASAD ABIDI/UNIVERSITY OF CALIFORNIA, LOS ANGELES

life when scanned, Josh Smith, an Intel researcher, has built a sensor that can collect environmental information and transmit it without a battery.

WHY IT MATTERS: Sensors that collect and transmit information are useful in many applications, such as tracking the temperature of food shipments. But most sensors require batteries; often, when the battery dies, the sensor needs to be replaced. Battery-free sensors could last much longer.

METHODS: The sensor uses an antenna similar to those found in battery-free RFID tags. When the sensor comes within range of an external device called an RFID reader, which emits radio waves, the antenna and circuitry harvest power from the radio signal to turn the sensor on. As long as the reader is within the antenna's range, the sensor collects and processes environmental information. The brain of the device is a microcontroller, requiring less than a milliwatt of power, that contains a 16-bit processor, eight kilobytes of flash memory, and 256 bytes of random-access memory.

NEXT STEPS: Currently, the sensing device must be within a meter of the reader to work, but Smith says that with minor changes to the way the microcontroller processes the data, the range can be extended to three meters or more. He and his team are also looking into integrating the microcontroller and antenna into a single chip to shrink the device.

BIOTECHNOLOGY

A Clue to Living Longer

Growth hormone and insulin may explain why restricting calories boosts longevity

SOURCE: "Targeted Disruption of Growth Hormone Receptor Interferes with the Beneficial Actions of Calorie Restriction"
M. S. Bonkowski et al.
Proceedings of the National Academy of Sciences 103(20): 7901–7905

RESULTS: Scientists at the Southern Illinois School of Medicine discovered that mice engineered to be resistant to growth hormone have a longer life span than normal mice; the increase is similar to that seen in normal mice fed a diet low in calories, but engineered mice fed a low-calorie diet showed no additional gain in longevity. Both the engineered mice and the calorie-restricted normal mice were much more sensitive to insulin, suggesting a possible mechanism for the increase in longevity.

WHY IT MATTERS: Scientists have long known that a low-calorie but nutritionally adequate diet can boost longevity in organisms as diverse as yeast, flies, and mice. But they don't know why. *(See "Is Defeating Aging a Dream?" p. 80.)* That the hormone-resistant mice mimic the longevity of calorie-restricted mice is an important clue to the mechanisms responsible for those effects. Scientists hope to one day design drugs that target the underlying biological pathway and thereby increase life span or treat age-related disease without dietary restrictions.

A mouse lacking the ability to respond to growth hormone (right) has a longer life span than a normal mouse (left).

METHODS: The scientists used genetically engineered mice that lacked the receptor for growth hormone. Engineered and normal mice were then fed a normal or a calorie-restricted diet.

NEXT STEPS: The researchers plan to investigate which of the many effects of caloric restriction lead to increased longevity. They will also test the hypothesis that insulin sensitivity is an important determinant of life span.

Microbial Drug Factories

Synthetically engineered microörganisms could provide a cheap way to manufacture drugs

SOURCE: "Production of the Antimalarial Drug Precursor Artemisinic Acid in Engineered Yeast"
D. K. Ro et al.
Nature 440(7086): 940–943

RESULTS: Dae-Kyun Ro, Jay Keasling (who wrote the "Notebook" entry on page 27), and colleagues at the University of California, Berkeley, have genetically engineered yeast to produce large quantities of artemisinic acid, a precursor to the malaria drug artemisinin.

WHY IT MATTERS: Artemisinin combination therapies are an effective treatment for malaria. But the drugs, which are derived from the sweet wormwood tree, are expensive and in short supply. More-efficient manufacturing methods could reduce the cost of the malaria drugs to the point that a larger number of people in poor countries could afford them. The work also illustrates the great potential of synthetic biology—the attempt to design and create organisms to perform specific functions.

METHODS: The researchers redesigned the metabolic pathways of yeast to more efficiently make an artemisinin precursor called amorphadiene, which plants naturally make in small quantities. Using a newly identified wormwood gene, they further engineered the yeast to complete the last few steps of the synthesis process to create artemisinic acid.

NEXT STEPS: Keasling's team will continue to fine-tune the system to make it even more efficient and therefore more cost effective. It will also scale up the manufacturing process in collaboration with Amyris Biotechnologies, a company in Emeryville, CA, that was founded to commercialize the technology. TR

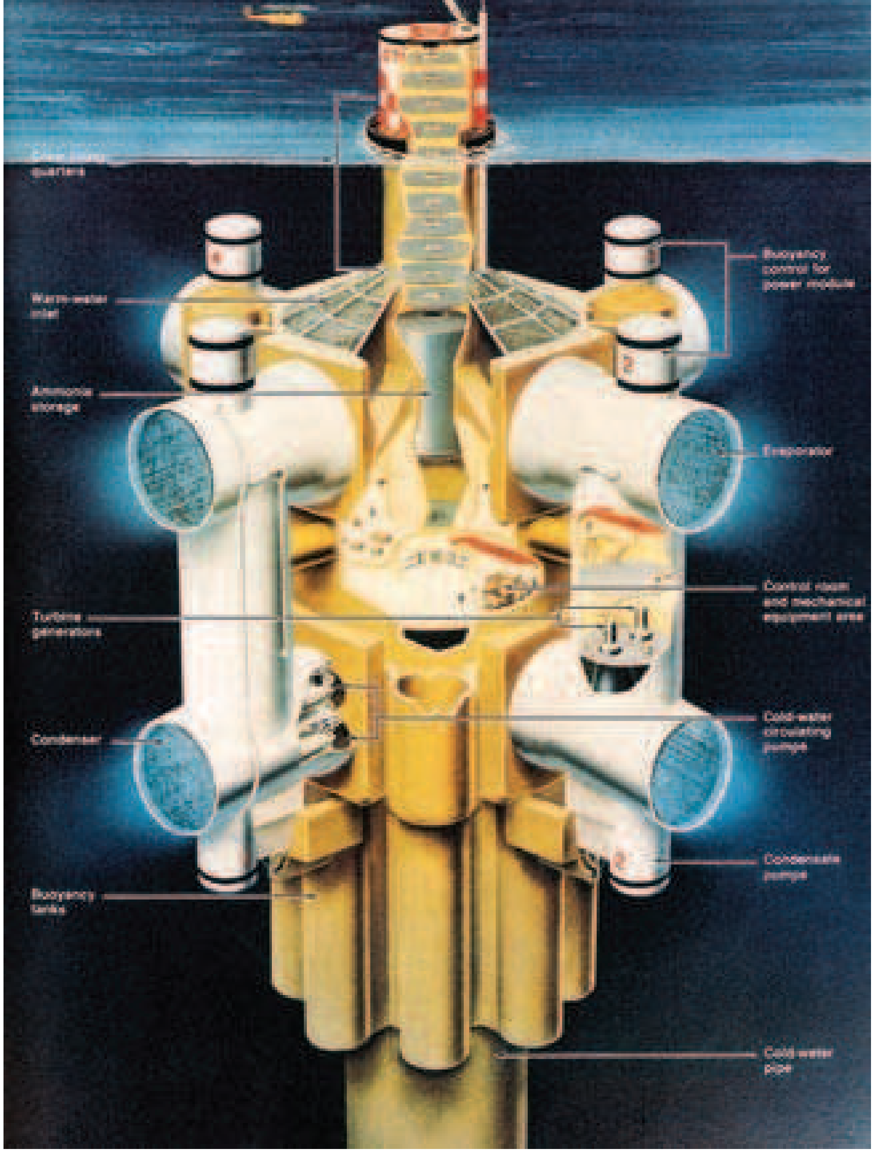
COURTESY OF MICHAEL BONKOWSKI

28 Years Ago in *TR*

Energy from the Sea

"Massive ocean thermal energy conversion plants may be turning this heat to usable electricity by 1985."

By Jessica B. Baker



LOCKHEED SPACE AND MISSILE CO., INC.

In the October 1978 issue of *TR*, William F. Whitmore invoked an idea from the 19th century: ocean thermal energy conversion, or OTEC. Exploiting the temperature difference between the sun-heated surface of tropical waters and the chilled depths thousands of feet below, Whitmore argued, could provide clean, renewable energy in the lower latitudes.

In the tropics, the oceans store an immense amount of energy from the sun. The band of surface water within 10° of the equator basks around at 80° F., while cold regions 3,000 ft. below are around 40° F. [OTEC] uses this thermal gradient, like the hot and cold terminals of a gas turbine, to generate electricity. The essence of the system is the circulation of a fluid such as ammonia or propane. Where it comes near the warm water it is brought to a boil and so expands; where it comes near the cold, it liquefies once again. In the course of its circulation from one place to another, it drives a power-generating turbine. A typical closed-loop system would include two exchangers (evaporator and condenser), a turbine, and a generator.

… The engineering challenges to be bridged demand solutions of scale rather than of technical innovation. Ship designs and structures used for offshore oil platforms have blazed the trail for the physical platform on which OTEC will be mounted. A general design goal is to isolate the platform as much as possible from the influence of the ocean surface, where the interaction of wind and wave can induce violent platform motions. A leading candidate is a large spar buoy configuration, with most of the platform mass several hundred feet underwater and a relatively small surface-piercing mast for access; this would also give warning to marine traffic. The OTEC system, with power cabled to shore, is necessarily fixed in place. Both steel and concrete are considered as possible platform construction materials.

In the 1990s, 250-kilowatt test facilities in Hawaii's tropical waters demonstrated OTEC's feasibility. For a plant to be commercially viable in the United States, however, it would have to produce between 50 and 100 megawatts. Developing such plants would require "patient financing," according to Luis Vega, test director of the largest test plant operated by the Pacific International Center for High Technology Research, which ran the Hawaiian facilities. The first step would be a prototype plant of a few megawatts. Ultimately, Vega believes, not only would a commercial-scale OTEC plant be viable, but it could operate at six to eight cents per kilowatt-hour, making it competitive with other renewable energy sources and even with fossil-fuel plants. But for now, the oceans remain untapped. TR

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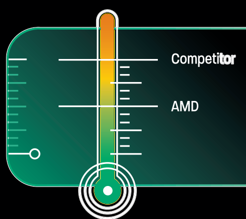

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